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A Serological Procedure for Identifying Strains of Gremmeniella abietina

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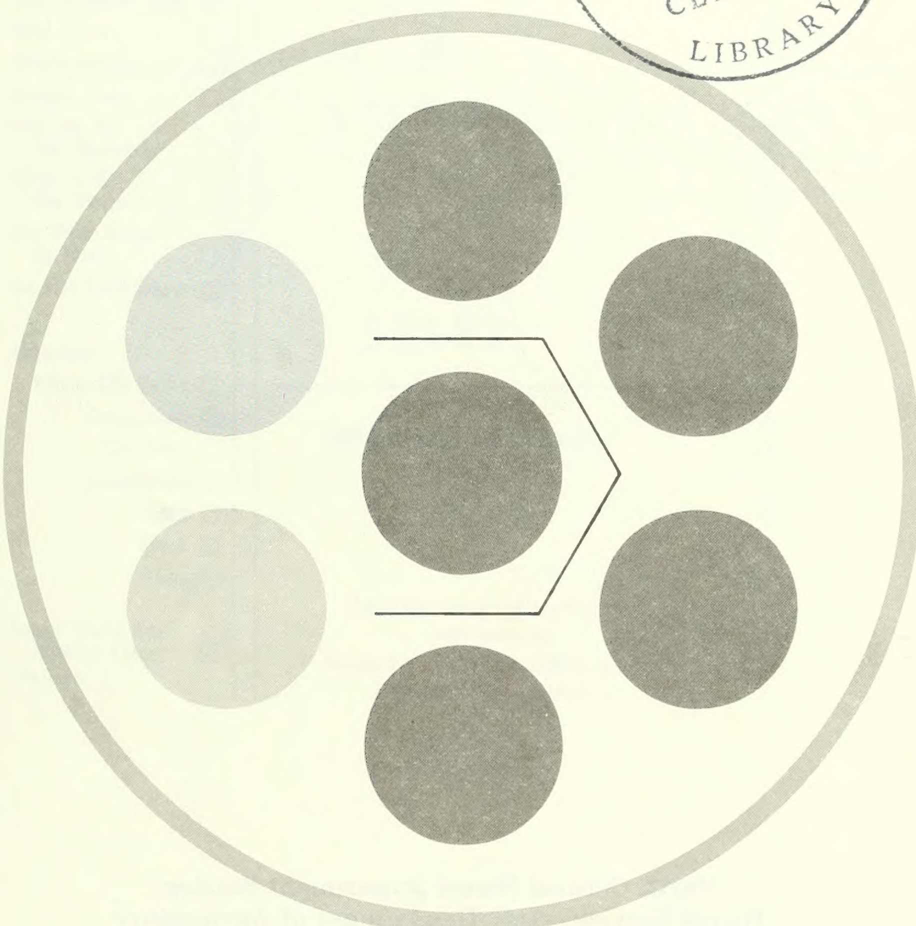

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PREFACE

As stated by Ball *et al.* (1974), "all serological tests for plant viruses (in our case, fungi) are modifications of the precipitin test in which a proteinaceous substance of a small molecular size combines with its specific antibody to produce an aggregate or precipitate that scatters enough light to be visible". Numerous serological techniques have been developed by investigators with various modifications. This manual uses the Ouchterlony double diffusion method. Other tests may be equally or more valuable depending on the situation.

Numerous individuals contributed in various ways to the development of this manual. We would like to acknowledge the assistance of Denise Dupont in the early development of our serology techniques. Dr. Thomas Nicholls, Michael Ostry, Dr. Mitchel Miller, and Professor Ernest Banttari also helped in the manual development and reviewed the final manuscript.

CONTENTS

A SEROLOGICAL PROCEDURE FOR IDENTIFYING STRAINS OF *GREMMENIELLA ABIETINA*

Darroll D. Skilling, *Principal Plant Pathologist,*
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INTRODUCTION TO THE SEROLOGICAL PROCEDURE

In 1977 Dorworth *et al.* determined that a newly discovered and highly virulent isolate of *Gremmeniella abietina* (Lagerb.) Morelet was present in northern New York State. Recent research has determined that this isolate is potentially one of the most serious diseases of conifers in North America. It has the ability to cause heavy losses in most pine species from seedlings to saw log trees. It also infects other conifers including spruce, fir, larch, Douglas-fir, and hemlock. The isolate of *G. abietina* found in New York was immunologically identical to isolates of this fungus from Europe but was different from all isolates of *G. abietina* found throughout the rest of North America. This isolate was called the European strain to distinguish it from the more common North American strain found in other areas of North America. Because the damage from the European strain is much more severe than that caused by the North American isolate and because the European strain is limited in its North American distribution, it has been placed under State and Federal quarantines in both the United States and Canada. In most cases this quarantine is specific to the European strain. As a result, it is necessary to identify the strain in newly infected areas before quarantine regulations can be established and enforced.

The objective of this manual is to describe a standard laboratory method developed to accurately identify strains of *G. abietina.* Several differences between the strains have been found and used to try to identify strains of *G. abietina.* These include growth rate, texture, and color of mycelial cultures; height of infection in host trees; and number of septations found in conidia. All of these characteristics have some value for identifying strains but none are completely reliable under all conditions. The only procedure that gives consistently reliable results is serology using the agar double diffusion test. The original serological technique for identifying strains of *G. abietina* was developed by Dorworth and Krywienczyk in 1975. This system has been adapted and refined at the North Central Forest Experiment Station and is presented here so that other forest pathology laboratories can use the technique to identify strains of *G. abietina* and, perhaps, strains in other fungus species.

The value of serological techniques and the antigen-antibody reactions is their specificity. An antibody will only combine with an antigen that contains amino acid sequences identical to that causing its formation in an animal. The production of virus antisera has been known for more than 50 years. In the 1940's the introduction of agar diffusion techniques made possible a procedure for determining not only the quantity but also the kinds of antigenic components within an antigen-antibody system (Ball 1974). In forest pathology, the use of serological techniques is more recent. Indications are that the serological techniques now used by plant virologists are adaptable with slight modifications to forest pathology fungi. The system outlined here is not limited to one species of fungi. With slight modification it appears that it will also identify strains within other species of fungi that may have developed slight genetic variations. Other serological methods can be used for this purpose. Fluorescent immunoassay and immuno-electrophoresis can, in many cases, give equal or better results. When possible investigators should try several tests to find the most useful and accurate method to solve a serological problem.

TEST MATERIAL

During 1980 and 1981 researchers at the North Central Forest Experiment Station screened 112 field isolates of *G. abietina* using the Ouchterlony double diffusion test. A total of 58 isolates were received from Canada; 34 from New York, Maine, and Vermont; and 20 from the Lake States. All of the isolates collected in the Lake States were identified to be the North American strain. Of the 92 isolates from Canada and the Northeast, 83 were the European strain. The isolates from Canada were also tested at the Great Lakes Forest Research Centre at Sault Ste. Marie, Ontario, as a check on the accuracy of the serological system. In more than 90 percent of these tests the results at the two laboratories were identical. In most cases any variation in the results of the two tests were either because the isolate was not *G. abietina* or because the isolate gave a positive reaction to both North American and European antiserum, which indicates that it had some characteristics of both strains. A confidence level of more than 90 percent in the area of race determination of higher fungi actually exceeds the rate of success one might expect in classical morphological determination of some problem fungi at the species level. Although the system is not as yet 100 percent accurate, identification errors are reduced as the procedure is improved. Although based on science, the serological process still has some aspects that can best be described as art. Until all the variables in this system are fully understood, some questions in results will continue. To avoid errors in strain identification, any deviation in readings between serology plates should be evaluated and discarded and the procedure should be rerun until results are consistent. With these precautions the accuracy rate should approach 100 percent.

This manual outlines the procedures used to handle field samples of *G. abietina* from the time they arrive at the laboratory until their strain is serologically identified.

HANDLING THE TEST ORGANISM AND PRODUCING ANTIGEN

Handling Quarantined Material

The European strain of *G. abietina* is under State and Federal quarantines so it is necessary to take additional safeguards when working with this organism. If the infected plant material is to be moved between States, it is necessary to obtain an interstate shipping permit (Plant Pest Quarantine Form 549) from the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Room 630, Federal Building, Hyattsville, MD 20782. The permit also requires the signed approval of the official responsible for quarantine regulations for the State receiving the sample. Each sample shipment must have a separate permit attached.

The primary hazard in working with an organism such as *G. abietina* is that the fungus may be spread into healthy areas. To avoid this, strict laboratory security procedures must be followed. All rooms in which the fungus is handled should be clearly posted with signs informing workers and the general public of the hazards involved. Any materials used in those rooms must be autoclaved when they are removed. In addition to autoclaving infected plant material and cultures, all material in waste containers should be autoclaved. Any liquid used in these areas in conjunction with isolations or serology should be collected in buckets for autoclaving before going into the drain system. Janitorial services are best handled by laboratory personnel with separate equipment. Floor debris should also be autoclaved. All fungus cultures should be kept in separate incubators with quarantine labels prominently displayed. Where possible, incubators should be kept locked as a further security measure.

Isolating *G. abietina* from Field Samples

Successful isolation of *G. abietina* from field samples depends on the care used in handling the sample prior to its arrival in the laboratory. *G. abietina* does not remain viable under high temperatures so sample material must be kept cool during shipment and storage. Samples collected during May and June will usually yield a high percentage of pure cultures of *G. abietina*. This is due in part to the presence of the fungus fruiting bodies during this period. Isolation from infected plant material during July and August is usually more difficult. It appears that *G. abietina* is not actively growing during this period and saprophytic fungi frequently are the dominant organisms present in the dead plant tissue. Aseptic removal of conidia or ascospores from these fruiting bodies will usually give a pure culture of the fungus in about 7 days when grown at 5°C (fig. 1). If fruiting bodies are not present, it is possible to isolate the fungus directly from newly infected plant tissue using standard pathological isolation procedures. Branches showing the characteristic green stain of *G. abietina* in the cambial zone are a good source of

Figure 1.—*Conidia of* G. abietina *on branch.*

isolation material. Wood chips containing *G. abietina* may be surface sterilized with a 1:10 hypochlorite solution (household bleach and water) for 1 minute, although this procedure is not always necessary (fig. 2). Although *G. abietina* will grow on standard malt agar media, it grows more rapidly if Campbell's V-8 juice[1] is substituted for 20 percent of the water (see Appendix). The fungus grows slowly at 25°C and will usually be overgrown by other fungi that invade tissue killed by *G. abietina* and that grow well at warmer incubation temperatures. To avoid this problem, the original isolations should be incubated at 5°C. At 5°, *G. abietina* is able to grow moderately while most of the commonly isolated saprophytic fungi are not. After a pure mycelial culture is obtained from the original transfer, it should be incubated at 15-17°C for optimum mycelial growth. Cultures grow well in the dark but should be grown under fluorescent light if asexual fruiting is desired.

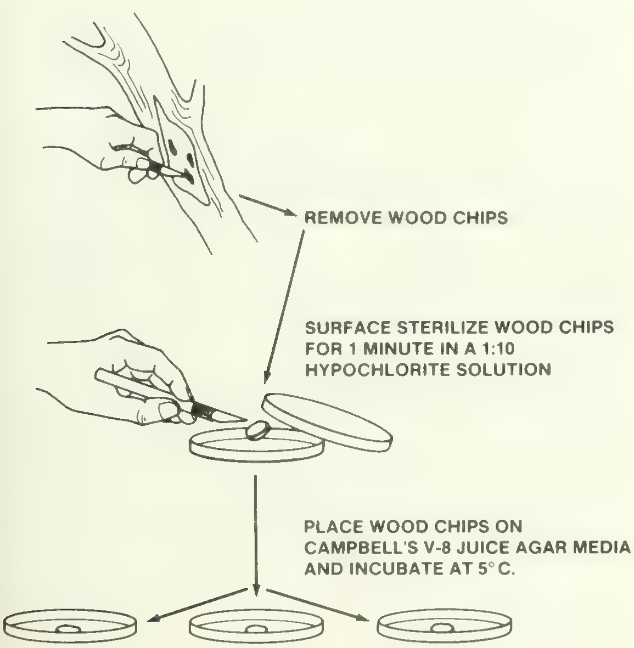


Figure 2.—*Method of isolating* G. abietina *from branches showing the characteristic green stain in the cambial zone.*

Growing *G. abietina* in Liquid Culture

Objective

Produce sufficient mycelium for homogenizing and extracting soluble antigens for protein determination.

G. abietina grows well in a liquid media consisting of Campbell's V-8 vegetable juice and glucose. Vegetable juice should be filtered to remove pulp before adding to media.

Materials

Several 10-inch sheets Miracloth (see Appendix)
420 ml/sample Campbell's V-8 juice (see Appendix)
8–foam stoppers/sample
8–100 ml beakers/sample
1–Buchner funnel 14 cm
8–500 ml Erlenmeyer flasks/sample
Several sheets GF-A filter paper 12.5 cm
Several sheets glass microfiber paper
20 g–D. glucose anhydrous (granular)
2–graduated cylinders
1–siphon hose
1–1,000 ml side-arm Erlenmeyer flask
1–500 ml plastic bottle/sample
1–2 liter flask

Procedure

A. Centrifuge 420 ml of V-8 juice per sample at 9,000 rpm for 10 minutes. Line the bottom of

[1]*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.*

the Buchner funnel with 1 layer of Miracloth and insert it into a 1,000 ml side-arm flask with vacuum line attached. Slowly pour the supernatant through the funnel.

B. Fill plastic bottles ⅔ full with filtrate and freeze to get additional separation of the vegetable pulp.

C. After freezing for about 8 hours, allow the plastic bottles with the filtrate to thaw undisturbed. During this time additional pulp will settle to the bottom of the bottles. After the pulp has settled, siphon off the supernatant into a 2-liter flask. Filter supernatant through a Buchner funnel under vacuum with a sheet of GF/A glass microfiber (see Appendix) paper on the bottom of the Buchner funnel.

D. To prepare growth media add 20 g glucose and 1,800 ml distilled water to 200 ml of V-8 filtrate. This is sufficient media for 8 flasks of one culture.

E. Dispense 250 ml of media into each of 8-500 ml Erlenmeyer flasks. Seal with with foam plugs and cover the flask necks with 100 ml beakers.

F. Autoclave immediately for 20 minutes at 15 psi to prevent bacterial growth in the media. If bacterial contaminates are present, the media will appear cloudy and should not be used.

G. After cooling, inoculate the flasks with mycelial plugs of the test organism taken from the margin of the mycelial colony. We use 4 or 5, $5mm^2$ plugs per flask.

H. Incubate the inoculated flasks in the dark at 17°C for 21 days. Shake flasks daily to aerate the mycelium and to break mycelial mats into smaller fragments for easier extraction.

Extracting Soluble Protein "antigens" from Mycelial Cultures

Objective

Remove soluble proteins from fungus mycelium grown in liquid culture.

This process involves separating mycelium from liquid media followed by washing and homogenizing mycelium in a cell homogenizer to break down the mycelial cell structure. The resulting soluble proteins (antigens) are then filtered from the homogenized mycelium.

Materials

A. For removing mycelium from liquid media:
Several 10-inch sheets Miracloth (see Appendix)
1–glass stirring rod/sample
1 pair–surgical gloves/sample
1–1,000 ml beaker/sample
Parafilm (see Appendix)
1–bucket for autoclaving all waste liquid
Ice chest and ice
1–150 ml beaker/sample
Triple-distilled H_2O

B. For homogenizing and centrifuging:
Braun MSK cell homogenizer (see Appendix) or other suitable homogenizer
1 or 2–60 ml/homogenizer flasks/sample[2]
1–glass rod/sample
2 liters–phosphate buffer 6.9 pH (see Appendix
CO_2 cylinder for homogenizer
1–250 ml plastic centrifuge bottle/sample
Refrigerated centrifuge
Ice chest and ice
Acetone (for rinsing)
Glass beads 1.00–1.05 mm (see Appendix)

C. For filtering:
1–500 ml side-arm flask/sample
1–prefilter, No. AP2504700 (see Appendix)/sample
1–Millipore filter assembly (see Appendix)/sample
1–250 ml flask/sample
Parafilm (see Appendix)
Ice chest and ice
Phosphate buffer 6.9 pH (see Appendix)
Triple-distilled water

Procedure

During the entire process of extracting soluble protein antigens, be careful to avoid contaminating mycelium with foreign proteins. All equipment must be clean and rinsed with triple-distilled water. Surgical gloves should be worn to avoid skin contact with the mycelium. Contamination can be a problem when several mycelial isolates are being extracted at the same time. Cross contamination with other samples will completely destroy the accuracy of the final serological reading. **Change gloves, beakers, and stirring rod after working with each sample.**

A. Filter liquid media and mycelium through 1 layer of Miracloth into a beaker. Pour (excess) fluid from beaker into a quarantine bucket to be autoclaved (fig. 3).

B. After filtering all 8 flasks of mycelium, carefully squeeze excess liquid from mycelium by twisting Miracloth.

[2]*Millipore assemblies and homogenizing flasks can be reused when washed 3 times with distilled water, twice with acetone, and then air-dried.*

Figure 3.—*Filter liquid media and mycelium through Miracloth and then pour excess fluid into a quarantine bucket.*

C. Rinse mycelium with triple-distilled water until rinse water remains clear to remove traces of growth media from mycelium. Stir and break up clumps of mycelium with a glass rod so that entire fungus mass is thoroughly rinsed.

D. Between rinsings and after last rinse, squeeze the Miracloth to remove the excess fluid from mycelium. All liquid must go into quarantine bucket.

E. Place mycelial pellet into a prelabeled beaker, cover with Parafilm and place on ice until it can be *homogenized.* **Do Not Freeze.**

F. Break up mycelial pellet with glass rod and add a small amount of phosphate buffer (pH 6.9) to moisten pellet.

G. Fill a 60 ml cell homogenizer flask one-half to two-thirds full of mycelium. Add 1 cm of glass beads. Add phosphate buffer until beads are just covered.

H. Place flask in homogenizer for 40 seconds or until mycelium is completely homogenized. Adjust CO_2 valve on homogenizer to keep mycelium cold but not frozen. Repeat operation if entire mycelial pellet has not been homogenized. Keep homogenized mycelium cold for the rest of the process by placing beakers on crushed ice.

I. Place homogenized mycelium and glass beads in a plastic centrifuging bottle. Residue left in flask should be rinsed out with distilled water into a quarantine bucket. Keep bottle with homogenized mycelium on ice until centrifuged. Centrifuge as soon as possible at 9,000 RPM for 10 minutes at 0°C.

J. **Use clean glassware for each sample. Do not cross-contaminate. Autoclave all equipment and liquid used to kill any viable mycelium that may remain.**

K. Place a Millipore assembly consisting of a prefilter No. AP2504700 over a screen (see Appendix) in a 500 ml side-arm Erlenmeyer flask attached to a vacuum line. After second centrifugation, filter the supernatant through the assembly. Pour liquid out slowly leaving glass beads and sludge in plastic bottle.

L. Rinse beads and sludge from plastic bottle so that bottle can be cleaned and reused.

M. Transfer filtrate (antigen) into 250 ml Erlenmeyer flasks, cover with Parafilm, and chill on ice. The antigens remain viable for up to 24 hours if kept cool (10°C). We strongly suggest that the protein level analysis be completed soon after harvesting and homogenizing so that the levels of nitrogen are at their optimum. This procedure is explained in detail in the following section.

Appendix

A. Isolating *G. abietina* from field samples
V-8 media for 4 samples
1. 45 g malt agar
2. 200 ml V-8 juice (unfiltered)
3. 800 ml distilled water
Mix all ingredients in a 1500 ml flask. Cover with foam stopper and 100 ml beaker. Autoclave for 20 minutes at 15 psi. In an aseptic pouring area fill petri dishes one half full with media. Store in 5° incubator until needed.

B. Growing *G. abietina* in liquid culture and extracting soluble proteins.
Materials and sources of supply:
Parafilm–Dixie marathon, Greenwich, CT 06830
Miracloth–Calbiochem, P.O. Box 17, Elk Grove, IL
V-8–Campbell product
GS-A-12.5 cm glass filter paper–Whatman Lab. Products, Inc.,Clifton, NJ
Braun MSK cell homogenizer and flasks–B. Braun Instruments, 807 Grandview Dr. South, San Francisco, CA 94080
Glass beads–size 1.00–1.05 mm–B. Braun Instruments

Millipore assembly–Millipore Corp., Bedford, MA 01730

Phosphate buffer
1. 1 liter distilled water
2. 13.61 g KH_2PO_4
3. 26.81 g NaH_2PO_4
4. 34.0 g NaCl
5. NaOH–or Hc1

- Combine first 4 ingredients
- Read pH on pH meter
- Adjust pH to 6.9 by adding NaOH or Hc1

PREPARING ANTIGENS FOR DOUBLE DIFFUSION TEST

Establishing a Standard Curve for Protein Level Analysis

Objective

Equalize the protein levels of culture samples necessary for the double diffusion test. This standardizing is accomplished by using a modified Lowry Test(s) that establishes a standard curve using optical density and parts per million of protein of the known protein solution. A standard curve is set up each time the protein analysis is run because there are influencing variables, i.e., exact amounts of reagents added to the unknowns, temperature changes, and age of chemicals used.

Materials

17–16 ml test tubes for standards and blanks
2–test tube racks
1–50 ml volumetric flask
3–100 ml beakers
1–250 ml graduated cylinder
1–500 ml repeating pipette calibrated in 5 ml
1–10 ml graduated cylinder
Known protein solution (see Appendix)
Copper reagent (see Appendix)
Folin (see Appendix)
Triple-distilled water
Balance
Spectrophotometer
Weighing paper
Magnetic stirrer
Test tube mixer
Disposable pipettes and dispenser
1 pipette for water
1 pipette for known protein solution
1 pipette for each antigen sample
Ice–(antigens must be kept at about 5°C)

Procedure

A. Arrange 6 sets of 16 ml test tubes in one of the 2 test tube racks in the following manner:
1. 2–16 ml tubes in row 1 (these are used to calibrate the spectrophotometer)
2. 3–16 ml tubes in rows 2, 3, 4, 5, and 6.

B. Weigh out 0.050 g of the Bovine Albumin (see Appendix). (This yields 1,000 ppm protein when added to 50 ml H_20).

C. Add the 0.050 g albumin to a volumetric flask and slowly mix in the 50 ml of triple distilled H_20. Mix the solution carefully because excessive bubbling will denature the proteins.

D. Set up a test series by pipetting the diluted Bovine Albumin into the test tubes.
1 ml = 1,000 ppm protein–row 2 (all 3 tubes)
0.8 ml = 800 ppm protein–row 3 (all 3 tubes)
0.6 ml = 600 ppm protein–row 4 (all 3 tubes)
0.4 ml = 400 ppm protein–row 5 (all 3 tubes)
0.2 ml = 200 ppm protein–row 6 (all 3 tubes)

E. Pipette the appropriate amount of triple-distilled H_20 to each set of test tubes to equal 1 ml (refer to table 1).

F. Following the establishment of the known protein series, prepare the antigens for the optical density test by adding the copper reagent, Folin (see Appendix), and water as described in the next section.

Preparing Antigens for Optical Density Test

Procedure

A. Set up three, 16 ml test tubes per fungus sample (to allow for additional readings and accuracy). Add 0.1 ml antigen and 0.9 ml triple-distilled water to each test tube. Use separate pipettes for each antigen sample. Label each sample.

B. Add 5 ml of the copper reagent (see Appendix) (using the repeating pipette) to all known protein

Table 1.—*Amounts of the known protein and triple-distilled water needed to obtain desired concentrations for the standard curve*

Tubes needed (number)	Desired amount known protein	Amount known protein added per tube	Triple-distilled H_20 added per tube
	ppm	*ml*	*ml*
2[1]	0	0	1
3	1,000	1	0
3	800	0.8	0.2
3	600	0.6	0.4
3	400	0.4	0.6
3	200	0.2	0.8

[1]Used to calibrate spectrophotometer.

Table 2.—*Test solutions in ml required to produce protein levels for preparing standard curve and antigens for optical density test*

Test solution	Desired protein level (ppm) 1,000	800	600	400	200
Protein solution	1	0.8	0.6	0.4	0.2
Distilled H_2O	0	0.2	0.4	0.6	0.8
Copper reagent	5	5	5	5	5
Folin reagent	0.5	0.5	0.5	0.5	0.5

standards and antigen samples (shown in table 2). Mix all tubes using a vibrating mixer.

C. Wait 10 minutes.

D. Pipette 0.5 ml of Folin reagent (see Appendix) into each standard and sample test tube (as shown in table 2).

E. Mix on vibrating mixer.

F. Wait 30 minutes. (The spectrophotometer should be turned on and calibrated according to directions at this time.)

G. Measure the known protein dilutions with the spectrophotometer to determine the optical density readings for each protein level. Record the optical density readings (as shown in table 3).

H. Run the antigen samples through the spectrophotometer to determine their optical density. Record these readings (as shown in table 4).

Table 3.—*Typical optical density readings for different protein levels of known solutions and antigen samples*

Desired protein (ppm)	Actual protein of known solution	Optical density[1] expressed in wavelength A	B	C
	ppm			
1,000	1,000	0.10	0.10	0.10
800	800	.80	.80	.80
600	600	.60	.60	.60
400	400	.40	.40	.40
200	200	.20	.20	.20
Antigen sample	Undetermined protein ppm			
A	—	.40	.42	.40
B	—	.67	.67	.68
C	—	.57	.58	.58

[1]The figures shown in this table are examples of the measurement of color intensity created by reagent and organic nitrogen. They are not to be used in calculations.

Table 4.—*Using the optical density wavelength of the unknowns to establish ppm of protein*

Sample	Optical density 1	2	3	Average	Graph reading
A	0.40	0.42	0.41	0.41	460
B	.50	.50	.51	.50	580
C	.65	.65	.66	.65	710

Calculating Concentrations of Antigen Protein

Procedure

A. After determining the optical density for the known protein solutions and the antigen samples, plot the optical densities for the known proteins (see fig. 4). Then, plot the average optical density of the three samples for each antigen.

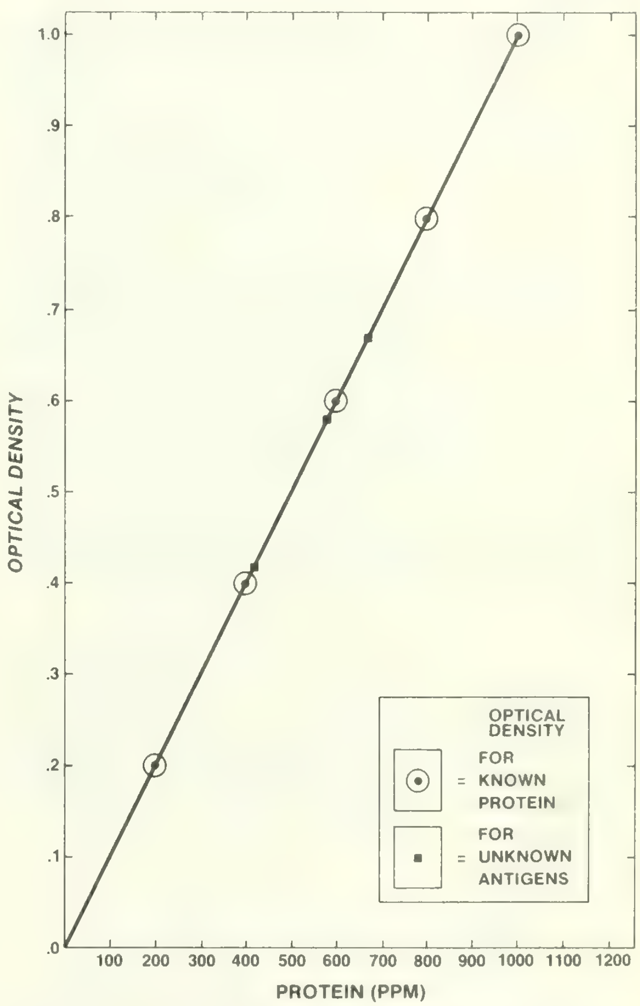


Figure 4.—*Determining protein concentration for assay*

Once the average is plotted, the parts per million of protein is achieved by reading across the standard protein graph to the regression line and down to the ppm numbers.

B. Because only 0.1 ml of antigen was used in this procedure (one-tenth concentration), multiply by 10 to determine the total concentration. This is the amount of protein in the sample.

Example: In table 3–Sample A has an optical density of 0.42

$$420 \times 10 = 4{,}200 \text{ ppm}$$

C. Bring all antigens to an equal concentration of 1,000 ppm. Because the desired ppm is 1,000, the ppm from sample A of 4,200 is 4.2 times as concentrated as needed. Therefore, the dilution factor equals 4.2 in this example.

$$\text{dilution factor} = \frac{\text{total concentration (ppm)}}{\text{desired concentration (ppm)}} =$$

$$\frac{4{,}200}{1{,}000} = 4.2$$

D. To dilute to the appropriate concentration of 1,000 it is necessary to multiply the dilution factor by this amount of antigen. This is the final volume to be obtained.

(total volume(ml) = dilution factor x desired volume of sample 1)
= 4.2 x 10 ml
= 42 ml

Example: Vol. diluting agent = 42 ml total volume–10 ml antigen = 32 ml of diluting agent (0.9 percent saline solution)

In this example, 32 ml of diluting agent is added to 10 ml of antigen that will be used to attain 1,000 ppm of antigen.

Diluting and Storing Antigen

Objective

To dilute the antigens obtained from liquid culture so they all have the same protein concentration. This is related to precipitation and intensity. Equalizing antigen proteins allows each antigen to react with the antibodies on an equal basis in the double diffusion plates.

Materials

1–2 ml pipette/sample
1–150 ml beaker/sample
1–250 ml beaker/sample for saline solution
1–250 ml graduated cylinder
0.9 percent physiological saline solution (see Appendix)

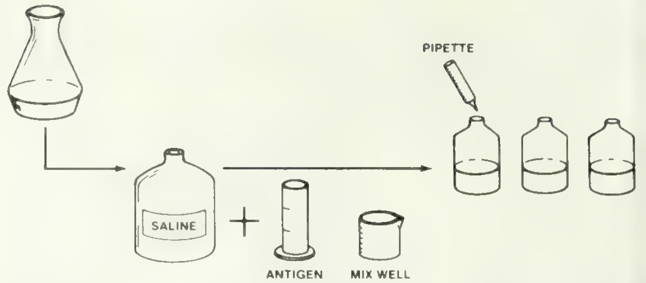


Figure 5.—*Diluting and storing antigen. (1) Plac 10 ml antigen in a flask. (2) Add the require amount of chilled saline solution as determine from the dilution calculations and mix completely (3) Pipette 2 ml diluted antigen into each half dram serum vial, label, and freeze immediately.*

Ice and container
Half dram vials (8/sample)

Procedure

Using the previously calculated dilution factors add the required amount of saline solution (dilutin agent) to each antigen sample.

A. Put 10 ml of antigen in a beaker (fig. 5). Add th required amount of chilled saline solution as de termined from the previous dilution calculations Mix completely.
B. Pipette 2 ml of diluted antigen into each half dram serum vial.
C. Label vials and freeze immediately.

Cross-Absorption of Antigens and Antibodies

Objective

Eliminate excess, non-characteristic proteins tha will interfere with the 'monospecific'[3] diffusion tes

We have discovered that the antiserum prepare against the antigen for the European strain of *C abietina* cross-reacts to some extent with the antige for the North American strain. (Likewise for the Nort American antiserum and the European antigen.)] appears that some of the protein groups of the Eu ropean strain are similar to those in the antigen fc the North American strain. The presence of thes common proteins when plated out in the double di fusion plates generates confusing precipitin banc that do not indicate identical strains of antigen t the antibodies, but rather a trace of *similar* protein

[3]*See glossary.*

The process of cross-absorption removes these unwanted proteins that are common to both strains using reciprocal absorption.

In our procedure two strains of *G. abietina* are involved. Antisera are prepared against each (as explained in Producing Antiserum Section). In the cross-absorption procedure for these two strains, two separate absorptions must be completed. North American antiserum is mixed with European antigen. The protein antibodies common to both strains react to form a precipitate that can be removed from the North American antiserum. This leaves only antibodies specific for the North American strain. The European antiserum is also mixed with the North American antigen. Again common protein antibodies are precipitated out leaving only antibodies that will react with proteins specific for the European strain.

To absorb all the common antibodies, and yet not dilute the serum more than necessary, the optimum proportions between the antiserum and the heterologous antigen must be determined. Through trial and error we have arrived at the following cross-absorption levels: 1 part North American antiserum + 2 parts European antigen; 1 part European antiserum + 1 part North American antigen.

Materials

Antiserum prepared against specific antigens
Antigens derived from fungus material
Centrifuge tubes–one for each antiserum
Centrifuge
Pipettes
Pipette dispenser

Procedure

Using the established levels of antiserum to antigen, combine both and mix gently in labeled centrifuge tubes (Fig. 6). Cover tubes with Parafilm (see Appendix), let stand upright in a test tube rack for 24 hours at room temperature. A noticeable precipitate forms that consists of the excess proteins not directly involved with the antibodies used in the analysis (Crowle 1961). Centrifuge the precipitate and pour off the supernatant, being careful not to resuspend any of the precipitate.

Now test the absorbed antiserum against further heterologous antigens as a check that absorption is complete, and against homologous antigens as a check for the presence of antibodies specific for the fungi being tested. (This test is incorporated in the double-diffusion plates—Ouchterlony Double Diffusion Method Section.)

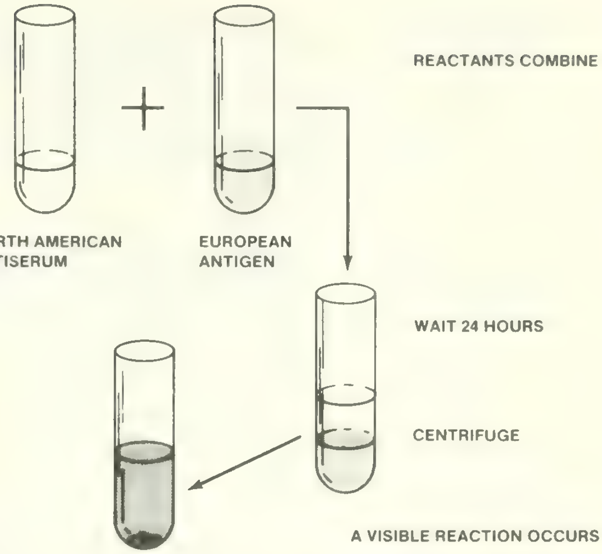


Figure 6.—*Cross-absorption of antigens to antiserum.*

Appendix

A. Source of known protein. Bovine Albumin (Fraction V) Eastman Kodak Co., Rochester, NY. 14650 Cat. #136 9750

B. Making the copper reagent–(for six or less samples).
   1. Combine the following three ingredients (in the specified amounts) and place in a repeating pipette that dispenses 5 ml.
      a. 250 ml of 2 percent Na_2C0_3 in 0.1N NaOH made by adding 20 g $NaC0_3$ and 4 g NaOH to 1 liter of distilled water.
      b. 2.5 ml of 2 percent $Na_2C_4H_4O_6$ (sodium tartrate) made by adding 20 g $Na_2C_4O_6$ to 1 liter of distilled water.
      c. 2.5 ml of 1 percent $CuS0_4$ (copper sulfate) made by adding 10 g $CuS0_4$ to 1 liter of distilled water.
   2. Mix all ingredients with a magnetic stirrer until dissolved.

C. Folin solution
   Pipette 0.5 ml phenol reagent (can be purchased from Fisher Scientific Co., Fair Lawn, New Jersey, under the name of Folin–Ciocalteau, solution 2n.)

D. Diluting and storing antigen
   Physiological saline solution–0.9 percent saline made by adding 9 g NaCl to 1 liter of distilled water.

PRODUCING ANTISERUM

Producing Antigens for Injecting Rabbits

Objective

To produce the required amount of antigen at 2,000 ppm protein level for injecting into rabbits to produce antibodies.

Materials

Fungus culture for producing antigen
24–500 ml Erlenmeyer flasks
Liquid growth media
Standard equipment for harvesting and homogenizing antigens
20 half-dram vials (sterilized)

Procedure

A. Using the procedure as outlined in the Handling the Test Organism and Producing Antigen Section (on growth in liquid culture), inoculate 24–500 ml Erlenmeyer flasks with the fungus culture that will be used to produce antibodies.
B. After approximately 21 days of growth in a 20°C dark incubator, harvest, homogenize, and filter the mycelial material as for regular antigen production as described in the Preparing Antigens for the Double Diffusion Test Section.
C. After determining the protein concentration, adjust the antigens to 2,000 ppm of protein (using the procedure outlined in the Preparing Antigens for the Double Diffusion Test Section).
D. Place antigen material in sterilized vials. Label and freeze until needed for injecting rabbits.

Injecting Antigens

Objective

Produce a homologous antiserum by injecting a complementary protein into a test animal.

Materials

2 New Zealand doe rabbits for each antiserum needed (see Appendix)
Freunds complete Bacto adjuvant (see Appendix)
Freunds incomplete adjuvant (see Appendix)
Soluble antigen
Hypodermic syringe–as specified by commercial lab
Needle–as specified by commercial lab

Procedure

Injecting fungus antigen into the rabbit stimulates the animals immune system to produce antibodies in direct response to the foreign protein. This antibody response is the basis of the serological system. After injecting antigens, the rabbit is checked periodically to determine the amount of antibody production (titer). This is done by a trial bleeding.

A. **Injection site information**—rabbit injection can be subcutaneous (under the skin), intraperitoneal (into the adbominal cavity), intravenous (into a vein), or intramuscular (into the muscle). The most effective method of antiserum production employs a combination of the listed injection sites.
B. **Adjuvant information**—an adjuvant is usually mixed with the antigen at the time of injection This stimulates and prolongs the immune response and increases antibody production. Because of variation in antibody production among rabbits, it is best to use at least two rabbits for each strain of antiserum being produced.
C. **Laboratory information**—although injecting rabbits with antigens and the subsequent bleedings are not difficult procedures, many laboratories do not have the necessary facilities for keeping the test animals. Several commercial laboratories (see Appendix) will handle this process for the serologist. The normal procedure is for the serologist to supply the test antigen and the injection schedule. If animal facilities are not available, this is probably the most economica way to obtain the necessary serum.
D. **Injection schedule**—schedules may vary in ac cordance to the serologist's needs. Although man schedules have been adapted for producing ar tibodies, the goal is to obtain a high titer (se Appendix) in the final serum. This antibody tite consists of the highest dilution of serum that wi give a reaction with an antigen. For our purpose a titer of 1:32 is extremely good–1:16 being th usual titer obtained. Anything lower than 1:8 i not acceptable.

Table 5 shows the injection schedule that has give the required titer in this study.

Harvesting and Storing Antiserum

Objective

Recover antibodies from the rabbit by obtainin blood and allowing it to clot, which makes it possibl

Table 5.—*A sample injection schedule that has given the necessary titer*

Day	Injection site	Amount injected	Material injected
		ml	
1	Intramuscular	1	Freunds complete Bacto adjuvant–minus antigen
	Intramuscular	1	Soluble antigen–minus adjuvant
11	Subcutaneous	1	Freunds incomplete Bacto adjuvant
	Subcutaneous	1	Soluble antigen
21	Intraperitoneal	1	Freunds complete Bacto adjuvant
	Intraperitoneal	1	Soluble antigen
23	—Trial bleeding to check titer—		
			(no adjuvant added)
31	Intravenous	½	Soluble antigen
35	Intravenous	1	Soluble antigen
39	Intravenous	1	Soluble antigen
43	Intravenous	1	Soluble antigen
45	—Final bleeding for serum—		

or serum to be separated from the clotted cells. This luid part of the blood (serum) contains the antibodes.

Procedure

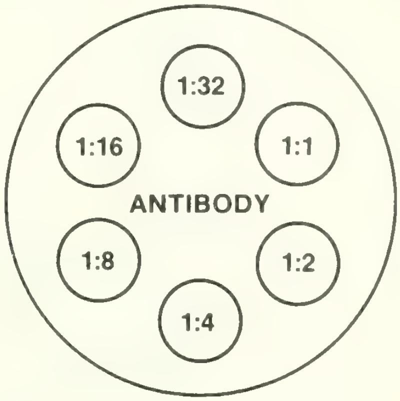
A. After extracting whole blood from the rabbit, let the blood sit in a covered beaker at room temperature for 1 to 2 hours until a clot forms.
B. Place the covered beaker at 4°C for 24 hours the clot will contract.
C. Decant the liquid serum from the beaker leaving the clot in the bottom. Save the clot. More serum can be extracted by letting the clot sit for an hour, then centifuging it for 10 minutes at 10,000 rpms.
D. Dispense the serum into vials, usually 1 to 2 ml per vial. Freeze vials immediately.

NOTE: Repeated freezing and thawing will impair the viability of the serum antibodies. If stored and sealed properly, the antiserum will remain viable for at least 12 months.

Appendix

A. Injecting antigens.
   New Zealand rabbits–5 lbs.
   Commercial laboratories–Green Hectares, 4583 Schneider Drive, Oregon, WI 53575.
   Hypodermic syringe.
   Freunds complete and incomplete adjuvant provided by the commercial lab.

B. Determining titer of antiserum.
   1. Use about ½ ml of the antiserum (keep the rest frozen).
   2. Label 6 vials–1:1, 1:2, 1:4, 1:8, 1:16, and 1:32.
   3. Using a micropipette gun, dispense 100 μl antiserum to 100 μl 0.9 percent saline solution (1:1), 100 μl antiserum to 200 μl saline (1:2), 100 μl antiserum to 400 μl saline (1:4), 100 μl antiserum to 800 μl saline (1:8), 25 μl antiserum to 400 μl (1:16), and 25 μl antiserum to 800 ; gml saline (1:32).
   4. Following dilution, mix the samples by inverting the vials.
   5. Test the titer by making several agarose gel diffusion plates as follows.



   6. Read the plates in about 48 hours. After inoculation, keep the plates at room temperature and do not move them.
   7. The titer is the highest dilution with a visible white precipitation band between the center well and the dilution well.

C. Diluting and storing antigen
   0.9 percent saline solution = 9 g NaCl/1 liter distilled water

D. Two dimensional Ouchterlony double diffusion plates.
   1. Petri dishes–50 mm x 9 mm
      Falcon, 1950 William Dr., Oxnard, CA 93030.
   2. Agarose media
      a. Combine the following two materials: 1 g–agarose–J. T. Baker Chemical Co., Phillipsburg, NJ, and 100 ml 9 percent physiological saline.
      b. Place in 600 ml beaker–place in a boiling water bath.
      c. Wait until solution is clear.
      d. Add 0.05 g sodium azide–NaN_3 FW 65.0 Practical grade J. T. Baker.

OUCHTERLONY DOUBLE DIFFUSION METHOD

Diffusion Plates and Design

Objective

Determine and identify responses between homologous antigen and antibody reactants that produce a line of precipitation where common proteins diffuse and meet in the gel. This is the final procedure used to determine the strain of *G. abietina*.

Materials

Agarose–sodium azide media (see Appendix)
Design for gel diffusion plate
4 mm diameter agar punch/cork borer
Disposable pipettes and dispenser
5 cm diameter tight lid plastic petri dishes

Procedure

Cut a series of wells into the gel diffusion plates and fill with the unknown antigens and the cross-absorbed serum. As these materials diffuse out from the wells, precipitation bands form between the wells of the antigen and the antiserum containing common proteins. Interpretation of these bands identifies the strain of the unknown antigen. The design and use of the diffusion plates can vary as long as the following rules are followed:

A. An antigen well must be placed opposite an antibody well so the two solutions can diffuse toward each other and allow a precipitate band to form if the antigen-antibody reaction takes place.
B. All outer wells should be equal in size and distance from the center well.

Preparing Double Diffusion Plates

A. Place 6 ml of warm agarose in each petri plate. After the agarose has solidified, place a paper pattern under each petri dish and cut the agar wells using the agar punch. Well diameter is 4 mm. The distance between the center well and each outer well is also 4 mm. Remove the agar plug from the wells by using a micro-suction or a micro-harpoon, being careful not to damage the sides of the agar well or to lift the agar from the bottom of the plate because solutions could leak into other wells.
B. Store unused gel plates at 3 to 10°C in an airtight container that has moist paper towels at the bottom. (The added moisture at the bottom allows for a longer storage period.)

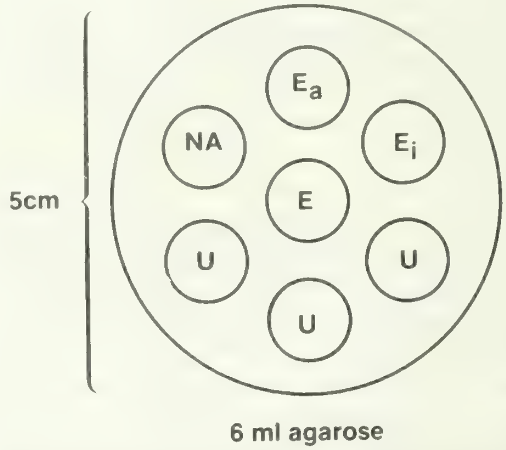
The Double Diffusion Plate Design

Figure 7 is an example of a pattern and labeling system for the gel diffusion plate used to determine the European strain of *G. abietina*.

Filling the Double Diffusion Plate Wells

When filling the plate wells, the following points should be remembered.

A. Fill the wells as quickly as possible because diffusion takes place rapidly.
B. Use at least three plates to determine each strain. This replication provides more accurate results.



E = **known European antiserum (previously cross-absorbed);**

E_a = **known European antigen used to make antiserum E;**

E_i = **known European antigen different from E_a;**

NA = **known North American antigen; and**

U = **unknown antigens to be tested.**

NOTE: Permanently mark the top and bottom of petr dish to identify positioning when the lid is removed.

Figure 7.—*Pattern and labeling system of the ge diffusion plate used to determine the Europea strains of* G. abietina.

Place equal amounts of antigen in each well for the best results. This is done by using micropipettes.

Avoid overflowing wells with antigen or antiserum, because this will give erratic readings.

Once the wells are filled, carefully replace the plate covers to avoid spilling the antigens and antiserum. Store in moist, tight containers at room temperature. Plates can be read in about 48 hours.

Interpreting Plates

Because cross-absorbed serum is used, the plate terpretation is simple. The petri dish offers a clear ew of the precipitin bands.

ocedure

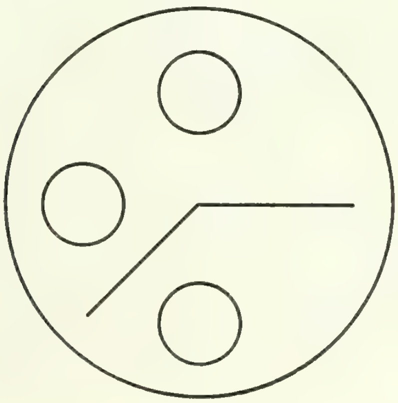
Approximately 48 hours after the wells are filled with antigens and antibody, diffusion will become visually complete. When plates are held over a light source, precipitin bands become distinguishable.

In the Ouchterlony method, the position of the precipitin bands indicates the antigen strain present in the well (fig. 8).

Analyzing Precipitin Bands

A *positive reaction* is indicated by a continuous precipitin band (fig. 8).

Negative reactions are indicated by precipitin bands that cross-over or have spurs. This may be a result of incomplete cross-absorption or an excess of antigen or antibody (figs. 9, 10).



gure 8.—*A continuous precipitin band indicates a positive reaction.*

Figure 9.—*Precipitin bands that cross-over indicate a negative reaction between two distinct antigens that react with a distinct antibody in the antiserum.*

Figure 10.—*Precipitin bands that form a spur indicate a negative reaction between two distinct antigens that are related but heterologous.*

Some examples of diffusion reactions when testing for the European strain of *G. abietina* (fig. 11).

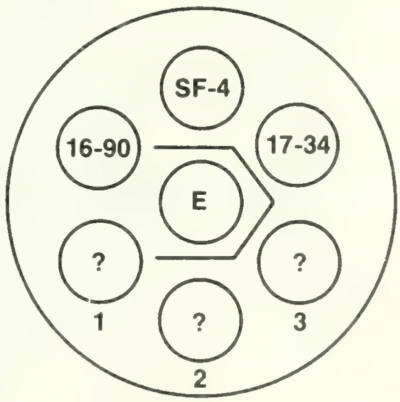


Figure 11a.—*All the antigens, except 16-90 and unknown #1 are reacting with the center wall. Because a visible precipitate is present at the interface of antibody and antigens of #2 and #3, the reaction indicates common proteins specific to the European strain of* G. abietina.

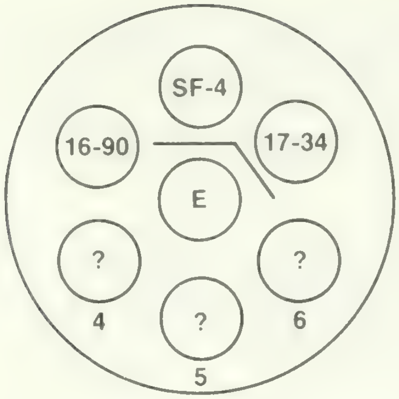


Figure 11b.—*None of the unknown antigens are reacting with the antibody. The only reactions occurring are between known homologous antigens. The unknowns in wells 4, 5, and 6 do not contain the protein specific to the European strain of* G. abietina.

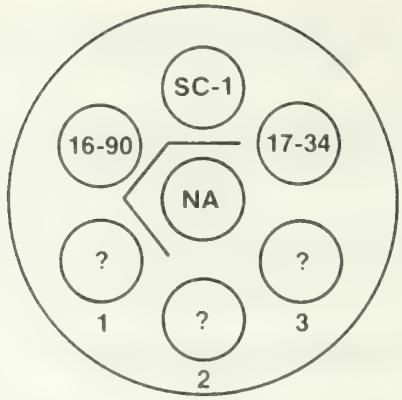


Figure 12a.—*Unknown antigen #1 is the only un known antigen (other than the known homologou antigens) that is reacting with the antibody. Th precipitan band at the interface of antigen and an tibody indicates proteins specific to the Nort American strain of* G. abietina.

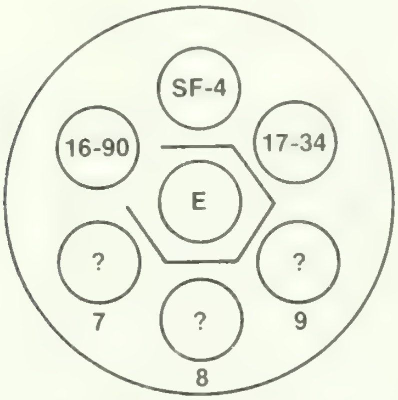


Figure 11c.—*All unknown antigens display a positive precipitate with the antibody, indicating common proteins. The known North American antigen 16-90 shows no reaction with the European antibody. The unknowns in wells 7, 8, and 9 contain the protein specific to the European strain of* G. abietina.

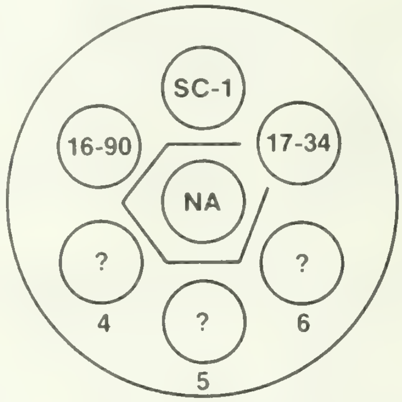


Figure 12b.—*All of the unknown antigens are re acting with the antibody and so are the know antigens except for the European strain. Wells 4 5, and 6, therefore contain the protein specific fo the North American strain of* G. abietina.

Some examples of diffusion reactions when testing for the North American strain of *G. abietina* (fig. 12).

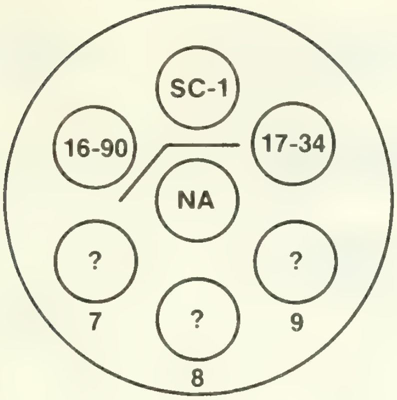


Figure 12c.—*None of the unknown antigens display a positive precipitate with the antibody, which indicates no common proteins specific to the North American strain of* G. abietina *in the double diffusion plate.*

GLOSSARY

Adjuvant—Substance added to antigens prior to injecting into a test animal to enhance activating properties and stimulate antibody production.

Antibody—A specific protein V-Globulin produced by an animal in direct response to the introduction of an antigen.

Antigen—A foreign protein that stimulates the production of specific antibodies when introduced into an animal.

Antiserum—Serum that contains antibodies.

Conidia—Small, asexual spores produced by fungi.

Cross-absorption—The process by which a portion of antibodies in an antiserum complex are precipitated out leaving only proteins specific to one strain.

Fluorescent immuno-assay—Procedure by which immune reactions can be observed at the cellular level. Reactions between antigen and antibody can be seen by using antibody conjugated to a fluorescent dye.

Fungus—A multicellular thallophyte that lacks chlorophyll.

Heterologous—Serological reactions in which the antigen tested is related but not the same as that which produced the antibody.

Homologous—Reaction that is identical to the antigen-antibody reaction of the antigen used to produce the antibodies.

Immunodiffusion—The separation of an antigen complex into discrete parts through difference in ability to pass through media.

Immunoelectrophoresis—A method using electrically charged particles to separate proteins in serum. Protein antigens are spread to specific areas along a line.

Immunology—Science of the immune response in animals.

Monospecific—Specific to only one antibody complex.

Mycelium—A mass of fungus filaments.

Ouchterlony Double Diffusion—The diffusion of both antigens and antibodies in a solid-liquid gel to form a precipitate at the interface.

Pycnidia—The fruiting bodies of certain fungi.

Proteins—Organic compounds of high molecular weight that contain nitrogen and yield amino acids on hydrolysis.

Serology—A branch of science that deals with the study of antigen-antibody reactions.

Serum—Cell-free and fibrin-free fluid expressed from clotted blood.

Titer—The strength of a solution as established through titration.

Titration—The measuring of how much of another substance it is necessary to add to a solution in order to produce a given reaction.

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A serological procedure for identifying strains of *Gremmeniella abietina*. Gen. Tech. Rep. NC-87. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 15 p.

This manual gives detailed laboratory serology procedures necessary to determine the identity of isolates of *Gremmeniella abietina* by the gel double diffusion method. The process is described from the arrival of the field sample to the reading of the precipitin bands on the diffusion plate.

KEY WORDS: Antigens, antibodies, double diffusion, mycelial cultures, titer, precipitin bands.

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Lake States Site Index Curves Formulated

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LAKE STATES SITE INDEX CURVES FORMULATED

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Site index is the commonly used method of estimating site quality in the United States. For most species in the eastern United States, site index is the average total height of dominant and codominant trees at a total age of 50 years. Height and age values from suitable site trees are related to site index curves for each species, and then interpolations or extrapolations are made to estimate site index. However, such graphical procedures are tedious and subject to error. More rapid, convenient, and accurate estimates of site index are possible using site index formulae with computers or with programmable hand-held calculators.

Site index formulae have been published for 11 Lake States site index curves (Lundgren and Dolid 1970). New site index curves based on stem analyses are now available for 12 species in northern hardwood stands (Carmean 1978). Among these are aspen and paper birch site curves that supersede those formulated by Lundgren and Dolid. In addition, we have converted the site curves for balsam fir and white spruce from breast height age to total age (Carmean and Hahn 1981a). Because of these changes, we have summarized the formulations for 21 site index curves now recommended for use in the Lake States (table 1). The formulations we have computed use a single equation model and are convenient for computers or for field use with programmable hand calculators.

Many formulations are based on the anamorphic form of the Richards (1959) growth functions, (Lundren and Dolid 1970; Carmean 1971, 1972; Monserud and Ek 1976).

This function can easily be solved for site index but is suited only to anamorphic site index curves. But stem analyses for many tree species show that tree height growth patterns and site index curves are usually polymorphic rather than anamorphic (Stage 1963, Carmean 1970). Therefore, accurate site index estimations require height growth models that describe these polymorphic patterns of tree height growth. Ek (1971), Payandeh (1974a, 1974b), and Monserud and Ek (1976) have suggested a more general and descriptive form of the Richards function that expresses polymorphic height growth.

$$H = b_1 S^{b_2} [1-e^{b_3 A}]^{b_4 S^{b_5}} \qquad (1)$$

where H = height, S = site index, A = age, e = base of the natural logarithms, and the b_i are regression parameters.

We chose this model to estimate tree heights, given age and site index, for all the Lake States species in this paper. Parameters for using this model are given in table 2.

Model (1) cannot be easily solved for site index, but an analogue of it suggested by Payandeh (1974b) provides a form for computing site index directly. Curves computed with this model may not pass exactly through the index tree height specified at the index age of 50 years, but this problem can be solved by using a weighted regression with a weight of [50-2 | AGE-50 |]. This procedure ensures close agreement at 50 years but with a slightly poorer yet acceptable fit at the extremes of age and site index. The following general formula was used for estimating site index, given age and height, for the Lake States species. Parameters for using this model are given in table 3.

$$S = c_1 H^{c_2} [1-e^{c_3 A}]^{c_4 H^{c_5}} \qquad (2)$$

where S, H, A, and e are as above and c_i are regression parameters.

Table 1.—*Species and data sources used in developing height and site index functions.*

Species[1]	Age range	Site index range	Data source
	Years	*Feet*	
Balsam fir (*Abies balsamea* (L.) Mill.)	20-90	20-70	Carmean and Hahn (1981a)
Red maple (*Acer rubrum* L.)	20-85	45-75	Carmean (1978)
Sugar maple (*Acer saccharum* Marsh)	20-95	45-75	Carmean (1978)
Yellow birch (*Betula alleghaniensis* Britton)	20-95	40-75	Carmean (1978)
Paper birch (*Betula papyrifera* Marsh)	20-100	45-70	Carmean (1978)
American beech (*Fagus grandifolia* Ehrh.)	20-95	45-60	Carmean (1978)
White ash (*Fraxinus americana* L.)	20-80	45-85	Carmean (1978)
Black ash (*Fraxinus nigra* L.)	20-100	50-80	Carmean (1978)
Tamarack (*Larix laricina* (DuRoi) K. Koch)	20-120	20-60	Gevorkiantz (1957e)
White spruce (*Picea glauca* (Moench.) Voss	20-130	20-70	Carmean and Hahn (1981a)
Black spruce (*Picea mariana* (Mill.) B.S.P.	20-120	20-60	Gevorkiantz (1957b)
Jack pine (*Pinus banksiana* Lamb.)	20-80	30-70	Gevorkiantz (1956)
Red Pine (*Pinus resinosa* Ait.)	20-120	40-70	Gevorkiantz (1957d)
White pine (*Pinus strobus* L.)	20-120	40-80	Gevorkiantz (1957c)
Aspen (*Populus* spp.)	20-75	55-85	Carmean (1978)
Black cherry (*Prunus serotina* Ehrh.)	20-100	40-80	Carmean (1978)
White oak (*Quercus alba* L.)	1-100	40-80	Carmean and Hahn (1981b)
Northern red oak (*Quercus rubra* L.)	20-100	50-75	Carmean (1978)
Northern white-cedar (*Thuja occidentialis* L.)	20-100	20-60	Gevorkiantz (1957a)
American basswood (*Tilia americana* L.)	20-95	45-80	Carmean (1978)
American elm (*Ulmus americana* L.)	20-100	45-80	Carmean (1978)

[1]Scientific names after Little (1953).

Table 2.—*Parameters for a height growth equation expressing height as a function of site index and age for published site index curves*[1]

Species	Parameters b_1	b_2	b_3	b_4	b_5	R^2	Standard error of mean (unweighted)	Maximum difference[2]
Balsam fir	2.0901	0.9296	-0.0280	2.8280	-0.1403	.99	0.54	1.7
Red maple	2.9435	.9132	-.0141	1.6580	-1.1095	.99	0.49	2.0
Sugar maple	6.1308	.6904	-.0195	10.1563	-.5330	.99	1.29	5.3
Yellow birch	6.0522	.6768	-.0217	15.4232	-.6354	.99	1.29	5.0
Paper birch	2.4321	.9207	-.0168	1.5297	-.1042	.99	1.06	4.2
American beech	29.7300	.3631	-.0127	16.7616	-.6804	.99	1.62	1.3
White ash	4.1492	.7531	-.0269	14.5384	-.5811	.99	1.37	5.1
Black ash	4.2286	.7857	-.0178	4.6219	-.3591	.99	.70	2.4
Tamarack	1.5470	1.0000	-.0225	1.1129	-.0000	.99	.52	1.4
White spruce	10.8738	.5529	-.0343	34.6880	-.6139	.99	2.33	7.2
Black spruce	1.7620	1.0000	-.0201	1.2307	.0000	.99	.52	1.9
Jack pine	1.6330	1.0000	-.0223	1.2419	.0000	.99	.50	1.1
Red pine	1.8900	1.0000	-.0198	1.3892	.0000	.99	.64	1.4
White pine	1.9660	1.0000	-.0240	1.8942	.0000	.99	.66	1.7
Aspen	11.4804	.5039	-.0291	105.9678	-1.0590	.99	1.31	4.9
Black cherry	5.0844	.6974	-.0250	20.7996	-.7114	.99	1.62	5.5
White oak	4.5437	.8170	-.0128	2.1089	-.1770	.98	4.25	([3])
Northern red oak	6.1785	.6619	-.0241	25.0185	-.7400	.99	1.31	4.9
Northern white-cedar	1.9730	1.0000	-.0154	1.0875	.0000	.99	.66	1.7
American basswood	4.7633	.7576	-.0194	6.5110	-.4156	.99	.70	2.7
American elm	6.4362	.6827	-.0194	10.9767	-.5477	.99	1.12	2.7

[1]Height $= b_1 S^{b_2} [1-e^{b_3 A}]^{b_4 S^{b_5}}$
S = Site index, A = Age, e = base of the natural logarithms.
[2]Maximum difference between site index estimated by the equation and the site index listed in published curves.
[3]Value not calculated because model was fitted to raw data rather than to site index curves.

Table 3.—*Parameters for a site index equation expressing site index as a function of height and age for published site index curves*[1]

Species	Parameters c_1	c_2	c_3	c_4	c_5	R^2	Standard error of mean (unweighted)	Maximum difference[2]
Balsam fir	0.2198	1.1644	-0.0110	-2.0364	-0.1775	0.99	1.10	3.1
Red maple	.3263	1.2186	-.0110	-2.0184	-.3180	.99	1.99	2.2
Sugar maple	.1984	1.2089	-.0110	-2.4917	-.2542	.98	1.90	6.7
Yellow birch	.1817	1.2430	-.0110	-2.0184	-.3180	.99	1.25	4.5
Paper birch	.5119	1.0229	-.0167	-1.0284	-.0049	.99	1.07	4.3
American beech	.2376	1.1312	-.0109	-1.8550	-.1430	.99	1.99	6.5
White ash	.1728	1.2560	-.0110	-3.3605	-.3452	.99	1.99	9.5
Black ash	.2388	1.1583	-.0102	-1.8455	-.1833	.99	0.51	3.4
Tamarack	.6464	1.0000	-.0225	-1.1129	.0000	.99	0.52	1.4
White spruce	.0833	1.3965	-.0196	-8.0895	-.3659	.98	3.22	9.8
Black spruce	.5675	1.0000	-.0201	-1.2307	.0000	.99	0.72	1.9
Jack pine	1.6124	1.0000	-.2233	-1.2419	.0000	.99	0.50	1.1
Red pine	.5291	1.0000	-.0193	-1.3892	.0000	.99	0.64	1.4
White pine	.5086	1.0000	-.0240	-1.8742	.0000	.99	0.66	1.7
Aspen	.1271	1.3330	-.0110	-4.8354	-.4568	.95	2.75	11.6
Black cherry	.1738	1.2707	-.0110	-3.5467	-.3823	.98	2.24	7.2
White oak	.4455	0.9895	-.0107	-0.9656	-.0004	.79	5.47	([3])
Northern red oak	.1692	1.2648	-.0110	-3.4334	-.3557	.97	2.09	7.8
Northern white-cedar	.5068	1.0000	-.0154	-1.0895	.0000	.99	0.66	1.7
American basswood	.1921	1.2010	-.0100	-2.3009	-.2331	.99	1.90	4.5
American elm	.1898	1.2186	-.0110	-2.6865	-.2717	.99	2.05	6.6

[1] $\text{Site} = c_1 H^{c_2} [1 - e^{c_3 A}]^{c_4 H^{c_5}}$
H = Total Height, A = Age, e = base of the natural logarithms.
[2] Maximum difference between site index estimated by the equation and the site index listed in published curves.
[3] Value not calculated because curves were fitted to raw data rather than to curved data.

The recommended site index curves used as data sources for 21 Lake States tree species are listed in table 1; the range of ages and the range of site indices for each of these species are also listed. No new site curve information is available for jack pine, red pine, white pine, black spruce, tamarack, and northern white-cedar. Therefore, our formulations for these species are based on the original Gevorkiantz site index curves and the parameters computed for these species by Lundgren and Dolid (1970), adding the values of 1.0 and 0.0 for parameters b_2 and b_5 respectively. The white oak curves are based on individual tree stem analyses gathered by Carmean (1971, 1972) in the Central States. We consider that these curves also apply to white oak in the Lake States. These original oak site index curves have been revised (Carmean and Hahn 1981b).

For the northern hardwood species (Carmean 1978) and for balsam fir and white spruce (Carmean and Hahn 1981a), data points for fitting the models were read directly from published site index curves over the ranges of ages and site indices indicated in table 1. Models (1) and (2) were then fitted to these readings using the weighted non-linear least squares procedures and the weights as described above. Table 2 lists the parameters and fit statistics for model (1) and table 3 lists the parameters and fit statistics for model (2). Each table lists the maximum difference between site index estimated by the equation and site index listed in the published site curves. These differences usually occur for the oldest trees on the best sites.

When these equations are used with a programmable calculator to estimate site index from age and total height, the parameters (table 3) and a simple program for solving the equation are entered and then stored. Estimates of site index can then be obtained by manually entering the species code, total height, and total age.

The standard precautions in using site index curves also apply in using these site index equations: site trees should be at least 20 years old and should be free growing, uninjured, dominant and codominant trees. Such trees commonly occur in well stocked, even-aged stands that have not been disturbed by past cutting. We recommend that increment cores for tree age be taken at breast height. Breast height age and total height should then be compared to the site index curves to estimate site class. D.b.h. age can be converted to total age by using the number

Table 4.—*Years to reach breast height by site index class*

	All classes	Site index class 20	30	40	50	60	70	80	90
	Years								
Balsam fir	—	15	15	13	11	10	9	8	8
Red maple	4	—	—	—	—	—	—	—	—
Sugar maple	4	—	—	—	—	—	—	—	—
Yellow birch	4	—	—	—	—	—	—	—	—
Paper birch	4	—	—	—	—	—	—	—	—
American beech	4	—	—	—	—	—	—	—	—
White ash	4	—	—	—	—	—	—	—	—
Black ash	4	—	—	—	—	—	—	—	—
Tamarack	—	12	10	7	5	5	5	5	5
White spruce	—	15	15	13	11	10	9	8	8
Black spruce	—	15	13	11	10	9	9	9	9
Jack pine	—	—	9	8	7	6	5	4	4
Red pine	—	—	10	8	6	5	4	4	4
White pine	—	—	12	12	12	10	8	6	5
Aspen	4	—	—	—	—	—	—	—	—
Black cherry	4	—	—	—	—	—	—	—	—
White oak	4	—	—	—	—	—	—	—	—
Northern red oak	4	—	—	—	—	—	—	—	—
Northern white-cedar	—	20	15	15	10	10	10	10	10
American basswood	4	—	—	—	—	—	—	—	—
American elm	4	—	—	—	—	—	—	—	—

of years specified by site class. Table 4 summarizes these values that are given in the original publications and/or that are used by the forest survey field crews. The resulting total age and total height values are then used to graphically estimate site index from the curves or to estimate site index with the formulae.

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Functions and parameters are given for computing site index for 21 Lake States tree species. Functions and parameters also are given for computing total height of dominant and codominant trees.

KEY WORDS: Equations, functions, computerized, tree height.

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User's Guide to Calculating Rate of Fire Spread

by Hand-Held Calculator

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USER'S GUIDE TO CALCULATING RATE OF FIRE SPREAD BY HAND-HELD CALCULATOR

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The programs in this guide use formulas developed by Simard *et al.*[1] to calculate the rate and direction of fire spread across any triangular or square plot. They can be used in the field with a hand-held Texas Instruments[2] TI-59 calculator. The first program is appropriate for use in a wildfire situation where three landmarks can be sighted and the time when the fire reaches each noted. After the fire passes, the angle and distances between the landmarks can be measured. The second program is best suited for prescribed burns where plot markers can be positioned ahead of time.

PROGRAM #1—THE TRIANGULAR PLOT

Given any triangle, let vertex A be the point the fire reached first (at time t_A), let vertex B be the point the fire reached second (at time t_B), and let vertex C be the point the fire reached last (at time t_C). Such a triangle can be placed on the xy-plane (fig. 1), with point A at the origin and B on the positive x-axis. Note that C can be in any one of the four quadrants.

Inputs needed are the two sides AB and AC, and the included angle A. Also necessary are the three times t_A, t_B, and t_C. The program calculates the rate of spread across the triangle and also gives the angle of spread θ with respect to the positive x-axis. For program listing and documentation, see Appendix I.

[1]*Simard, A. J.; Eenigenburg, J. E.; Adams, K. B.; Nissen, R. L.; Deacon, A. G. A general procedure for sampling and analyzing wildland fire spread. Forest Science (in press).*

[2]*Use of trade name does not constitute endorsement of the product by USDA Forest Service.*

USER INSTRUCTIONS

Step	Enter	Press	Display
1[1]	angle A	A	1/tan A[2]
2	side AB	B	AB
3	side AC	C	AC
4a	t_A	D	$-t_A$
b	t_B	R/S	t_B
c	t_C	R/S	t_C
5		E	rate of spread
6		R/S	angle of spread[3]
		([4])	

[1]Steps 1 through 4 may be entered in any order as long as all are done before step 5. In step 4, the three times must be entered in chronological order.

[2]If angle A equals plus or minus 90°, angle A will be displayed rather than l/tan A.

[3]Relative to a base line between A and B.

[4]If the user wishes to see the rate of spread again after viewing the angle, pressing R/S will cause the program to return to step 5 without reexecuting the entire program. To change one or more of the inputs and rerun the program, only the steps involved need be changed before pressing E again. Changing one of the times of step 4 requires reentering all three times. The display will remain fixed in the decimal configuration of the last output. To return to standard display, enter the sequence INV FIX.

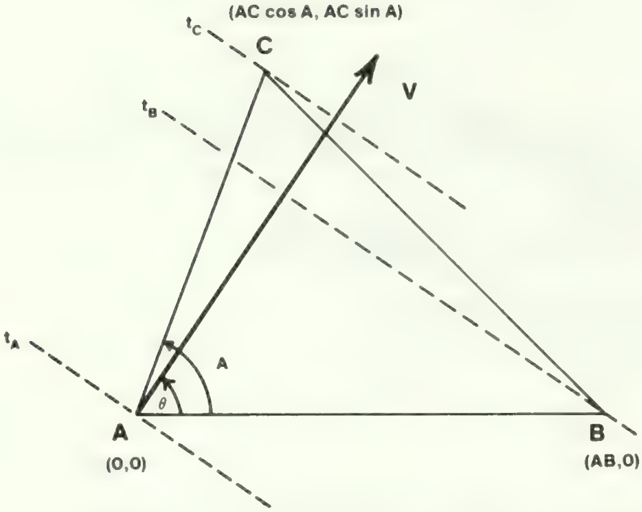

Figure 1.—*The triangular plot.*

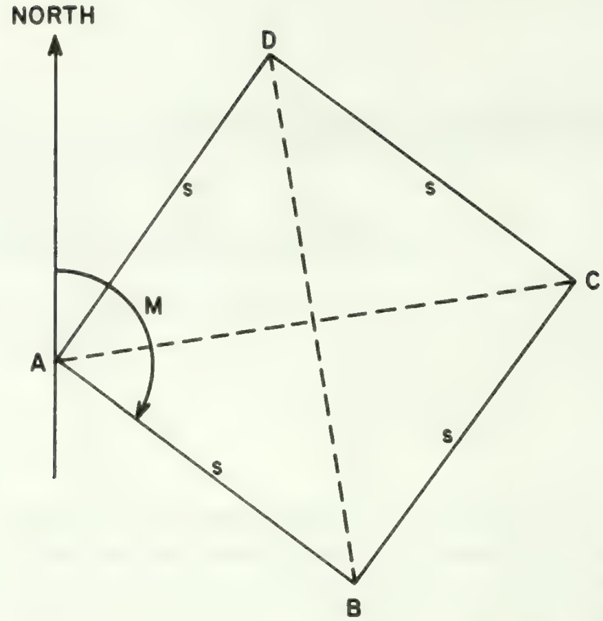

Figure 2.—*The square plot.*

Sample Run

Three landmarks are sighted during a wildfire and the times when the fire reaches each is noted: 2.0 minutes, 3.6 minutes, and 4.2 minutes. The three landmarks are labeled A, B, and C, respectively. The distance between A and B is 45 feet, between A and C, 63 feet, and angle A measures 78°.

Step	Enter	Press	Display
1	78	A	.2125565617
2	45	B	45.
3	63	C	63.
4a	2	D	-2.
b	3.6	R/S	3.6
c	4.2	R/S	4.2
5		E	22.05
6		R/S	38.

Output from the program shows the fire spreading at 22 ft/in at an angle of 38° with respect to side AB.

PROGRAM #2—THE SQUARE PLOT

The four corners of the square are labeled A through D (fig. 2). It does not matter which vertex is labeled A, as long as the order is counterclockwise. Angle M is the azimuth of B as viewed from A.

Inputs needed are the time when the fire reaches each corner of the square, the length of a side of the square s, and the azimuth M.

Define triangle A as that formed by ABC, triangle B by BCD, triangle C by CDA, and triangle D by DAB.

The program calculates the rate of spread ROS and compass direction for each triangle and averages them to produce a rate and compass direction for the square. Standard deviations of the rate and direction of spread may also be obtained.

The program also calculates a vector average to test variability. Here the rate and direction of spread for each triangle is treated as a vector. The four vectors are added and the resultant vector divided by four. The vector average gives the rate of spread in the indicated direction. The closer this number is to the arithmetic average, the less variable the direction and/or rate of spread.

For program listing and documentation, see Appendix II.

USER INSTRUCTIONS

Step	Enter	Press	Display
1[1]	time at point A	A	t_A
2	time at point B	B	t_B
3	time at point C	C	t_C
4	time at point D	D	t_D
5	side of square	E	S
6	azimuth M	R/S[2]	average ROS across square
7		R/S	average direction across square
8		R/S	standard deviation of ROS
9		R/S	standard deviation of direction
-		([3])	
10a[4]		A'	ROS across triangle A
b		R/S	direction across triangle A
11a		B'	ROS across triangle B
b		R/S	direction across triangle B
12a		C'	ROS across triangle C
b		R/S	direction across triangle C
13a		D'	ROS across triangle D
b		R/S	direction across triangle D
14a		E'	vector ROS across square
b		R/S	vector direction across square
-		([5])	

[1]Steps 1 through 4 may be entered in any order as long as all are done before step 5.

[2]The program makes all calculations at this point before displaying the arithmetic average rate of spread. This takes approximately 45 seconds.

[3]Pressing R/S at this point will cause a jump to step 14.

[4]Steps 10 through 14 may be executed in any order and repeated at will.

[5]Pressing R/S at this point will cause a jump to the output of step 6 without reexecuting the entire program. This may be followed by step 7, etc., if the user so wishes. The user can rerun the program with new data or restart the program from any point merely by returning to step 1. Unlike the triangular plot program, all inputs (even if they are the same as the previous run) must be reentered. The display will remain fixed in the decimal configuration of the last output. To return to standard display, enter the sequence INV FIX.

Sample Run

A square plot, 10 feet on each side, is laid out prior to a prescribed burn. Each corner is labeled counterclockwise, A to D, with the azimuth of side AB equal to 135°. The fire reaches point B first at a time of 5.0 minutes, point C at 5.3 minutes, point A at 5.33 minutes, and point D at 5.54 minutes.

Step	Enter	Press	Display
1	5.33	A	5.33
2	5	B	5.
3	5.3	C	5.3
4	5.54	D	5.54
5	10	E	10.
6	135	R/S	26.34
7		R/S	357.
8		R/S	3.71
9		R/S	8.
10a		A'	22.42
b		R/S	357.
11a		B'	26.03
b		R/S	6.
12a		C'	31.36
b		R/S	356.
13a		D'	25.57
b		R/S	347.
14a		E'	26.17
b		R/S	357.

The output from this sample run is as follows:

	Rate of spread	Compass direction of spread
	Ft/min	*Degrees*
Square		
Arithmetic	26	357
Vector	26	357
Triangle		
ABC	22	357
BCD	26	6
CDA	31	356
DAB	26	347
STANDARD DEVIATION	4	8

APPENDIX I

The Triangular Plot Program

```
000  76 LBL
001  11   A
002  42 STO
003  11  11
004  29  CP
005  32 X:T
006  42 STO
007  00  00
008  09   9
009  00   0
010  67  EQ
011  30 TAN
012  94 +/-
013  67  EQ
014  30 TAN
015  32 X:T
016  30 TAN
017  35 1/X
018  42 STO
019  00  00
020  76 LBL
021  30 TAN
022  91 R/S
```

Rearranging terms for computational convenience, the formula for the angle of spread θ given by Simard *et al.* is:

$$\theta = \tan^{-1}\left[\left(\frac{AB}{t_B - t_A}\right)\left(\frac{t_C - t_A}{AC \sin A}\right) - \left(\frac{1}{\tan A}\right)\right],\ t_B \neq t_A.$$

The program first checks to see if angle A equals 90° (step 010) or −90° (step 013). If so, then 1/tan A equals 0. A zero is stored in memory register 00 R00 at steps 006-007 for this purpose. If angle A does not equal ±90°, then 1/tan A is calculated and stored in R00 (steps 015-019).

```
023  76 LBL
024  12   B
025  42 STO
026  12  12
027  91 R/S
028  76 LBL
029  13   C
030  42 STO
031  13  13
032  91 R/S
```

Sides AB and AC are read in with labels B and C and stored in R12 and R13 respectively.

Since we need t_B - t_A and t_C - t_A, first a negative t_A is stored in R22 and R23, then t_B is added to R22 and t_C to R23.

```
033  76  LBL
034  14   D
035  94  +/-
036  42  STO
037  22   22
038  42  STO
039  23   23
040  91  R/S
041  44  SUM
042  22   22
043  91  R/S
044  44  SUM
045  23   23
046  91  R/S
```

At this point all inputs have been entered into the calculator. Placing side AC in the t-register and angle A in the display permits taking advantage of the calculator's built-in vector feature. P/R at step 054 calculates the y-coordinate of this vector, which equals AC sin A. Dividing by t_C - t_A (steps 055-057) gives us the reciprocal of (t_C - t_A)/(AC sin A), which is stored in R30.

```
047  76  LBL
048  15   E
049  43  RCL
050  13   13
051  32  X:T
052  43  RCL
053  11   11
054  37  P/R
055  55   ÷
056  43  RCL
057  23   23
058  95   =
059  42  STO
060  30   30
```

The next section of the program evaluates AB/(t_B - t_A). First, a check is made to see if $t_B = t_A$. If so, a special case exists and a jump is made to label SIN.

Otherwise, AB/(t_B - t_A) is calculated. Since this is also an intermediate value of the spread rate calculation, it is stored in R21 before continuing. This value is then divided by (AC sin A)/(t_C - t_A) which has been stored in R30, and finally (1/tan A) from R00 is subtracted. Taking the arctan in steps 079-080 yields θ, which is stored in R3l.

The rate of spread of a fire across a triangular plot given by Simard *et al.* is:

$$r = \frac{AB \cos \theta}{(t_B - t_A)}, \; t_B \neq t_A.$$

Cos θ is taken at step 083 and multiplied by AB/(t_B-t_A) from R21. This is stored in R30 before jumping to label A', where the output is displayed.

```
061  29  CP
062  43  RCL
063  22   22
064  67   EQ
065  38  SIN
066  35  1/X
067  65   ×
068  43  RCL
069  12   12
070  55   ÷
071  42  STO
072  21   21
073  43  RCL
074  30   30
075  75   -
076  43  RCL
077  00   00
078  95   =
079  22  INV
080  30  TAN
081  42  STO
082  31   31
083  39  COS
084  65   ×
085  43  RCL
086  21   21
087  95   =
088  42  STO
089  30   30
090  61  GTO
091  16  A'
```

```
092  76 LBL
093  38 SIN
094  09   9
095  00   0
096  42 STO
097  31  31
098  43 RCL
099  30  30
100  77  GE
101  16 A'
102  50 IxI
103  42 STO
104  30  30
105  09   9
106  00   0
107  94 +/-
108  42 STO
109  31  31
```

If t_B equals t_A, the fire is spreading perpendicular to the x-axis. In this case, θ equals $\pm 90°$ and the rate of spread equals the absolute value of $(AC \sin A)/(t_C - t_A)$.

The latter value had previously been calculated in steps 049-058 and stored in R30. A positive 90° is first stored in R31. The rate is checked at step 100 to see if it is positive. If not, its absolute value is taken at step 102 and stored in R30, and the angle -90° is stored in R31.

```
110  76 LBL
111  16 A'
112  43 RCL
113  30  30
114  58 FIX
115  02  02
116  91 R/S
117  43 RCL
118  31  31
119  58 FIX
120  00  00
121  91 R/S
122  61 GTO
123  16 A'
```

The output is displayed in the same units that the inputs were given in. Two decimal places are allowed for the user working in chains/hour. The user working in feet/minute should round to the nearest whole foot. The angles are output to the nearest degree. Steps 122-123 are added so that the output sequence can be repeated.

APPENDIX II

The Square Plot Program

```
000  76 LBL
001  16 A'
002  43 RCL
003  22  22
004  58 FIX
005  02  02
006  91 R/S
007  43 RCL
008  23  23
009  58 FIX
010  00  00
011  91 R/S
012  76 LBL
013  17 B'
014  43 RCL
015  24  24
016  58 FIX
017  02  02
018  91 R/S
019  43 RCL
020  25  25
021  58 FIX
022  00  00
023  91 R/S
024  76 LBL
025  18 C'
026  43 RCL
027  26  26
028  58 FIX
029  02  02
030  91 R/S
031  43 RCL
032  27  27
033  58 FIX
034  00  00
035  91 R/S
036  76 LBL
037  19 D'
038  43 RCL
039  28  28
040  58 FIX
041  02  02
042  91 R/S
043  43 RCL
044  29  29
045  58 FIX
046  00  00
047  91 R/S
```

The first part of the program is actually used last. Since the program pointer always starts at location 000 when searching for a label, all user-defined labels are found within the first 100 steps. To further reduce execution time, absolute addressing is used rather than labels for all branching operations.

The code at left outputs the final results. The rates of spread for triangles A through D are stored in even-numbered registers 22 through 28 and are output to two decimal places to satisfy users working in chains/hour. Users working in feet/minute should round to the nearest foot. The angles are stored in odd-numbered registers 23 to 29 and are output to the nearest degree.

```
048  76 LBL
049  10 E'
050  43 RCL
051  30  30
052  58 FIX
053  02  02
```

R30 and R31 contain the vector averages for the rate and direction. Steps 060-062 show a jump to location 457, where the mean and standard deviation for both the rate and direction of spread are output.

```
054  91 R/S
055  43 RCL
056  31  31
057  58 FIX
058  00  00
059  91 R/S
060  61 GTO
061  04  04
062  57  57
063  76 LBL
064  11  A
065  42 STO
066  01  01
067  42 STO
068  05  05
069  42 STO
070  12  12
071  91 R/S
```

The input labels come next. As each time is entered, it is stored in three different registers because each corner of the square is associated with three different triangles.

```
072  76 LBL
073  12  B
074  42 STO
075  02  02
076  42 STO
077  09  09
078  42 STO
079  10  10
080  91 R/S
```

The program pages through the registers in reverse order, starting with R12. R12, R11, and R10 contain times for points A, C, and B, respectively, indicating that triangle A is processed first.

R09, R08, and R07, containing times for triangle B, are processed next. Triangle C is third, followed by triangle D.

```
081  76 LBL
082  13  C
083  42 STO
084  06  06
085  42 STO
086  07  07
087  42 STO
088  11  11
089  91 R/S
090  76 LBL
091  14  D
092  42 STO
093  03  03
094  42 STO
095  04  04
096  42 STO
097  08  08
098  91 R/S
099  76 LBL
100  15  E
101  42 STO
102  13  13
103  91 R/S
104  42 STO
105  14  14
106  02  2
107  02  2
```

Label E stores the length of one side of the square in R13, and the azimuth in R14.

```
108  42 STO
109  15  15
110  01  1
111  02  2
112  42 STO
113  00  00
114  00  0
115  42 STO
116  30  30
117  42 STO
118  31  31
119  42 STO
120  32  32
121  42 STO
122  33  33
```

R15 is used for indirect addressing. Whenever a rate of spread or a direction is calculated, R15 contains the address where it should be stored. It is originally set to 22.

R00 is also used for indirect addressing. It is originally set at 12 and is intended to input the correct triangle to the program as noted above. R30 to R33 are cleared for later summations.

The main loop of the program (steps 123-352) is executed four times, once for each triangle. Since the process is the same on each, for clarity this discussion will use the notation of the first triangle. As noted above, the times for the first triangle are brought into the loop in the order t_A, t_C, t_B. The notation $\min(t_A,t_C)$ is used to indicate the lesser of t_A and t_C, while $\max(t_A,t_C)$ is used to indicate the greater of the two.

The general formula for the angle of spread across a right isosceles triangle (Simard *et al.)* is:

$$\theta = \tan^{-1}\left[\alpha\left(\frac{t_3 - t_1}{t_2 - t_1}\right) - \beta\right], \; t_2 \neq t_1, \text{ where}$$

t_1, t_2 and t_3 are the three times in chronological order, and α and β are constants dependent on the specific case involved (fig. 3).

Each case can have a subcase consisting of its mirror image. To differentiate between the two, the first group is called a and the reflected group b. Steps 123-188 identify the particular case and subcase as well as place $(t_3 - t_1)$ in R19 and $(t_2 - t_1)$ in R20.

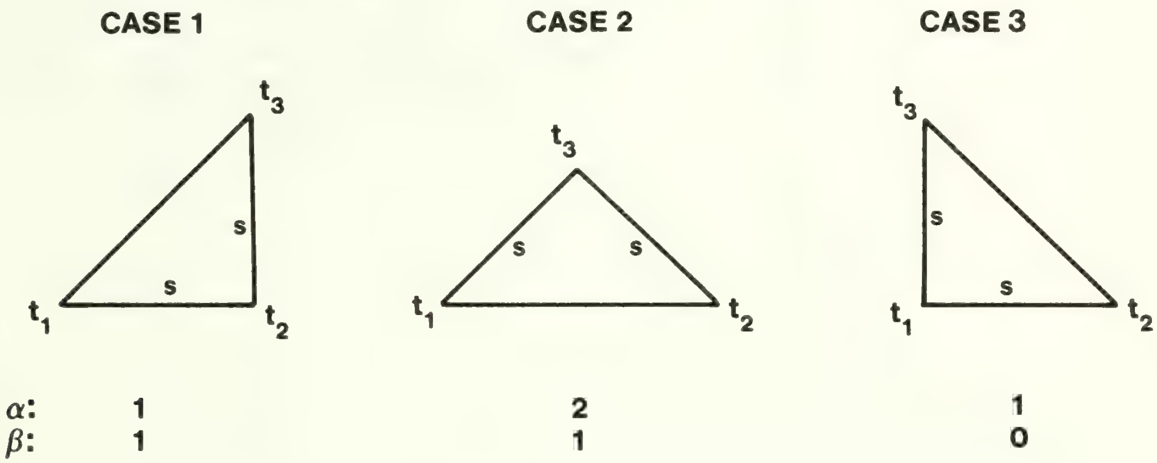

Figure 3.—*The three right isosceles triangles.*

```
123  86  STF
124  01   01
125  01   1
126  42  STO
127  17   17
128  42  STO
129  18   18
130  73  RC*
131  00   00
132  32  X:T
133  01   1
134  94  +/-
135  44  SUM
136  00   00
137  73  RC*
138  00   00
139  42  STO
140  19   19
141  77   GE
142  01   01
143  50   50
144  32  X:T
145  42  STO
146  19   19
147  22  INV
148  86  STF
149  01   01
150  01   1
151  94  +/-
152  44  SUM
153  00   00
154  73  RC*
155  00   00
156  42  STO
157  20   20
158  77   GE
159  01   01
160  70   70
161  00   0
162  42  STO
163  17   17
164  32  X:T
165  48  EXC
166  20   20
167  61  GTO
168  01   01
169  84   84
```

The sequence begins by setting flag 1, which is used to separate case a from b. A one is then stored in R17 and R18, indicating β and α respectively.

Next t_A is recalled (steps 130-131) and entered into the t-register. RC* at step 130 does not appear on the calculator's keyboard. It is achieved by entering the sequence RCL IND.

The program then recalls t_C (steps 133-138), stores it in R19, and tests it against t_A (step 141). If t_C is less than t_A, their locations (t-register and R19) are switched (steps 144-146) and flag 1 is reset (steps 147-149), indicating case 1b, 2a, or 3a.

Then t_B is recalled (steps 150-155) and stored in R20. If it is less than the time currently in the t-register, $\min(t_A,t_C)$, then the triangle is case 3 and β (R17) is set equal to zero (steps 161-163), $\min(t_A,t_C)$ is moved to R20, and t_B is placed in the display (steps 164-166) before jumping to step 184.

```
170  32  X:T
171  48  EXC
172  19   19
173  77   GE
174  01   01
175  82   82
176  42  STO
177  20   20
178  02   2
179  42  STO
180  18   18
181  32  X:T
182  48  EXC
183  19   19
184  94  +/-
185  44  SUM
186  19   19
187  44  SUM
188  20   20
```

If, on the other hand, t_B is greater than $\min(t_A,t_C)$, it passes the test at step 158, causing a jump to step 170. The program moves t_B to the t-register, $\min(t_A,t_C)$ to R19, and $\max(t_A,t_C)$ to the display (steps 170-172).

A test is made at step 173, and if $\max(t_A,t_C)$ is greater than t_B, the triangle is case 1, and a jump is made to step 182.

If $\max(t_A,t_C)$ is less than t_B, the triangle is case 2, $\max(t_A,t_C)$ is placed in R20, α (R18) is set equal to two, and t_B is moved to the display (steps 176-181).

Both case 1 and case 2 execute steps 182-183 and succeed in placing the maximum time, t_3, in R19, and the minimum time, t_1, in the display. All three cases come together at step 184, where t_1 is made negative and added to t_3 in R19 and t_2 in R20 (steps 185-188).

```
189  29  CP
190  43  RCL
191  20   20
192  67   EQ
193  02   02
194  22   22
195  43  RCL
196  18   18
197  65   ×
198  43  RCL
199  19   19
200  55   ÷
201  43  RCL
202  20   20
203  75   -
204  43  RCL
205  17   17
206  95   =
207  22  INV
208  30  TAN
209  42  STO
210  21   21
211  39  COS
212  65   ×
213  43  RCL
214  13   13
215  55   ÷
216  43  RCL
217  20   20
218  65   ×
219  61  GTO
220  02   02
221  32   32
```

The program now calculates θ. If $t_2 = t_1$, $\theta = 90°$. This special case is processed with a test at step 192 and a jump to 222, where 90° is stored as the angle. All other cases are handled with steps 195-210.

The formula for the rate of spread (Simard *et al.*) is:

$$\mathrm{ROS} = \frac{s \cos\theta \sqrt{\alpha}}{(t_2 - t_1)},\ t_2 \neq t_1,$$

where s is the length of a side of the square. ROS is calculated in steps 211-221 and 232-235.

```
222  09   9
223  00   0
224  42  STO
225  21   21
226  43  RCL
227  13   13
228  55   ÷
229  43  RCL
230  19   19
231  55   ÷
232  43  RCL
233  18   18
234  34  √x
235  95   =
236  72  ST*
237  15   15
238  42  STO
239  34   34
240  44  SUM
241  32   32
242  33  x²
243  44  SUM
244  33   33
245  01   1
246  44  SUM
247  15   15
```

If we are dealing with the special case where t_2 equals t_1, the formula for the rate of spread is:

$$\mathrm{ROS} = \frac{s}{(t_3 - t_1)\sqrt{\alpha}},$$

which is calculated in steps 226-235.

ROS is stored indirectly in the register indicated by R15. ST* at step 236 does not appear on the calculator's keyboard. It is achieved by entering the sequence STO IND. ROS is also stored in R34 for later vector calculations and summed in R32, with its square summed in R33 for later standard deviation calculations.

θ is stored in R21 for subsequent azimuth calculations.

```
248   32  X:T
249   43  RCL
250   17   17
251   67   EQ
252   02   02
253   72   72
254   87  IFF
255   01   01
256   02   02
257   65   65
258   09    9
259   00    0
260   94  +/-
261   75    -
262   61  GTO
263   03   03
264   07   07
265   01    1
266   08    8
267   00    0
268   85    +
269   61  GTO
270   03   03
271   07   07
272   43  RCL
273   18   18
274   67   EQ
275   02   02
276   95   95
277   87  IFF
278   01   01
279   02   02
280   88   88
281   01    1
282   03    3
283   05    5
284   75    -
285   61  GTO
286   03   03
287   07   07
288   04    4
289   05    5
290   94  +/-
291   85    +
292   61  GTO
293   03   03
294   07   07
```

The general formula for finding the compass direction of spread DOS is: DOS = $N \pm \theta + M$, where $N \pm \theta$ is dependent on the case involved. Steps 248-306 begin the calculation with N + or N -, followed by a jump to 307 for $\theta + M$.

Cases 1 and 2 pass the test at step 251 and jump to 272. Steps 258-264 are for case 3a and 265-271 for case 3b.

Case 3a: DOS = $-90° - \theta + M$.

Case 3b: DOS = $180° + \theta + M$.

Cases 1 and 2 are tested again at step 274. Case 1 passes and jumps to 295. Case 2a is handled in steps 281-287 and case 2b in steps 288-294.

Case 2a: DOS = $135° - \theta + M$.

Case 2b: DOS = $-45° + \theta + M$.

```
295  87  IFF
296  01   01
297  03   03
298  05   05
299  09   9
300  00   0
301  85   +
302  61  GTO
303  03   03
304  07   07
305  00   0
306  75   -
307  43  RCL
308  21   21
309  85   +
310  43  RCL
311  14   14
312  95   =
313  32  X:T
314  43  RCL
315  34   34
316  32  X:T
317  37  P/R
318  44  SUM
319  30   30
320  32  X:T
321  44  SUM
322  31   31
323  32  X:T
324  22  INV
325  37  P/R
326  32  X:T
327  93   .
328  05   5
329  94  +/-
330  32  X:T
331  77   GE
332  03   03
333  39   39
334  85   +
335  03   3
336  06   6
337  00   0
338  95   =
```

Case 1b is processed in steps 299-304 and case 1a in 305-306.

Case 1b: DOS = 90° + θ + M.

Case 1a: DOS = 0°−θ + M.

All cases come to step 307, where θ is either added to or subtracted from the previous calculation and added to the original azimuth M.

Steps 313 to 322 change polar to rectangular coordinates. The y-values are summed in R30 and the x-values in R31.

Steps 323-325 return the angle to polar within the field -90° ≤ DOS<270°.

Angles which are negative have 360° added to them in steps 326-338.

```
339   72  ST*
340   15   15
341   01   1
342   44  SUM
343   15   15
344   09   9
345   00   0
346   94  +/-
347   44  SUM
348   14   14
349   97  DSZ
350   00   00
351   01   01
352   23   23
353   43  RCL
354   31   31
355   55   -
356   04   4
357   95   =
358   32  X:T
359   43  RCL
360   30   30
361   55   -
362   04   4
363   95   =
364   22  INV
365   37  P→R
366   32  X:T
367   42  STO
368   30   30
369   93   .
370   05   5
371   94  +/-
372   32  X:T
373   77   GE
374   03   03
375   81   81
376   85   +
377   03   3
378   06   6
379   00   0
380   95   =
381   42  STO
382   31   31
```

The angle is stored indirectly to the location address that is stored in R15.

Because triangle B is rotated 90° from triangle A, and C is rotated 90° from B, etc., 90° is subtracted from the azimuth M at this point before returning to the beginning of the main loop at step 123.

Finally, after the main loop is executed four times, once for each triangle, the program arrives at step 353.

The vector averages are calculated in steps 353-382, with the rate of spread stored in R30 and the angle of spread, after converting to positive degrees, stored in R31.

```
383  75  -
384  01  1
385  08  8
386  00  0
387  95  =
388  42  STO
389  11  11
390  85  +
391  03  3
392  06  6
393  00  0
394  95  =
395  42  STO
396  12  12
397  04  4
398  42  STO
399  00  00
400  42  STO
401  03  03
402  00  0
403  42  STO
404  04  04
405  42  STO
406  05  05
```

A problem may arise when calculating standard deviations, if the angles are close to 0°. For example, 355° and 0° are only 5° apart, yet their magnitudes are 355° apart. To avoid this problem, 180° is subtracted from the vector average for a lower bound and stored in R11. Then 180° is added to the vector average as an upper bound and stored in R12.

After preparing R00 to R05 for statistics calculations, each angle is checked to see if they lie within the bounds.

```
407  02  2
408  03  3
409  42  STO
410  15  15
411  43  RCL
412  11  11
413  32  X:T
414  73  RC*
415  15  15
416  77  GE
417  04  04
418  24  24
419  85  +
420  03  3
421  06  6
422  00  0
423  95  =
424  32  X:T
425  43  RCL
426  12  12
427  32  X:T
428  22  INV
429  77  GE
430  04  04
431  37  37
432  75  -
433  03  3
434  06  6
435  00  0
436  95  =
437  44  SUM
438  04  04
439  33  X²
440  44  SUM
441  05  05
442  02  2
443  44  SUM
444  15  15
445  97  DSZ
446  00  00
447  04  04
448  11  11
```

If outside the bounds, 360° is either added to or subtracted from the angle before summing. However, the original angle stored in registers 23 to 29 remains unchanged.

Each of the four angles of spread ±360°, are summed in R04 and their squares summed in R05.

```
449  43 RCL
450  32  32
451  42 STO
452  01  01
453  43 RCL
454  33  33
455  42 STO
456  02  02
457  79  x̄
458  58 FIX
459  02  02
460  91 R/S
461  32 X:T
462  58 FIX
463  00  00
464  91 R/S
465  22 INV
466  79  x̄
467  58 FIX
468  02  02
469  91 R/S
470  32 X:T
471  58 FIX
472  00  00
473  91 R/S
474  61 GTO
475  10 E'
```

Each of the four rates of spread and their squares previously summed in steps 240-244 are now entered into R01 and R02.

Using the calculator's built-in functions for calculating the mean and standard deviation, each can be displayed by repeatedly pressing the R/S key. First is the mean of the rates, then the mean of the directions, then the standard deviation of the rates, and finally the standard deviation of the directions.

Pressing R/S once more causes a jump to label E', where the vector averages are output. Although pressing label E' accomplishes the same thing, this feature was added to eliminate one keystroke for user convenience.

Eenigenburg, James E.
User's guide to calculating rate of fire spread by hand-held calculator. Gen. Tech. Rep. NC-89. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 16p.

Presents TI-59 programs that use fire arrival times to calculate the rate and direction of spread of a fire across a triangular or square plot.

KEY WORDS: Programs, plot, vector, wildfire, prescribed burn.

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Forest Service

North Central Forest Experiment Station

General Technical Report **NC-90**

A Fire Effects Appraisal System for Wisconsin

Ross W. Gorte and David C. Baumgartner

Crops
Timber
Wildlife
Recreation
Ornamental Trees
Environmental Quality
Equipment and Improvements

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A FIRE EFFECTS APPRAISAL SYSTEM FOR WISCONSIN

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The rising cost of fire management and the rising value of resources have stimulated concern with appraising the economic effects of wildfire on forest and associated land. Many existing fire effects appraisal systems are limited to estimating economic losses to timber, structures and equipment, and range resources. Appraisal systems are greatly needed that recognize and display the full range of positive and negative fire effects on forest and associated land.

Recent work to establish improved fire effects appraisal systems (e.g., Crosby 1977, Marty and Barney 1981) and to determine the economic efficiency of alternative fire management strategies (e.g., Schweitzer, Anderson and Mills 1982; Simard 1976) have been oriented toward the needs of public land managers. These managers have long term management plans and responsibilities as well as ready access to a good deal of historical, current, and future plan data to provide inputs for evaluations. Appraisal systems designed for these needs are complex, require a lot of data, and consider that value changes resulting from wildfires on public land have an economic impact on the general public over long time periods. The wildfire effects appraisal systems oriented toward public land may not be completely and directly applicable to the immediate needs of individual States that are responsible for fire control and management on private land. The States, especially those in the northeastern United States where most forest land is in small, private ownerships, need to focus on appraisal in terms of economic impact on individual owners in the short term. Few small, private landowners have concrete, long-term management plans for their forests, and few fires in the Northeast have an important impact on the public. Most States are also limited in the amount of time available for wildfire effects appraisal and in the amount of training that can be given to appraisers. The States, therefore, require appraisal systems that are as accurate as possible given time and training constraints, acceptance by field personnel, and the availability of input data. Simplicity and flexibility are crucial for early field acceptance and application. The State systems can then be improved as more complex and theoretically correct systems are refined and tables of expected average value changes for a wide range of fire types, sizes, cover types, and areas are developed over a period of years.

In Wisconsin, wildland fire damage appraisals are frequently used in insurance settlements and legal proceedings. Fire management officials have had legal embarrassments with unsupported values obtained with the previous system, which was developed in 1938. The old system had severe limitations for appraising immature timber stands, particularly plantations. Another problem with the old system is that an arbitrary loss of one dollar per acre was assigned for recreation and wildlife and another dollar loss per acre for site deterioration. In addition, no specific instructions were provided for appraising damage to crops, equipment and improvements, ornamental trees, aesthetics, environmental quality, or developed recreation sites.

Recognizing these shortcomings, the Wisconsin Department of Natural Resources (DNR) formed a "Fire Fuels and Effects Committee" in 1977 to develop an improved system. They enlisted the aid of the North Central Forest Experiment Station, and a cooperative research effort between the Station and the Michigan State University Forestry Department was established to develop an improved system. This report describes that system.

The primary purpose of the new system is to provide accurate wildfire effects appraisal information that would be defensible in court. Certain constraints were imposed by the Committee to ensure a practical system for Wisconsin. The system should be reasonably simple and should take no more than 1 hour to complete for an average fire. It should also make the best possible use of currently existing Wisconsin data.

Researchers reviewed alternative economic approaches and suggested a theoretical framework for each value component of the system. The Wisconsin DNR Fire Fuels and Effects Committee reviewed, and often modified, each value component in terms of their needs for information and the various constraints such as the amount of time and skill available to make appraisals. They were able to see how the system would fit into the existing fire management organization and to evaluate its administrative acceptability. They were also very familiar with Wisconsin resources and the availability of data.

THE FIRE EFFECTS APPRAISAL SYSTEM[1]

Resource Elements

The new system includes the following seven resource elements or value components:

- Timber
- Wildlife
- Recreation
- Ornamental Trees
- Environmental Quality
- Crops
- Equipment and Improvements

Recreation is divided into effects on aesthetics and effects on developed recreation sites. Effects on undeveloped recreation are incorporated into the wildlife element. Because the primary purpose of the system is credibility in court, value changes for most of the resource elements are expressed in terms of their impact on individual owners. Value changes for wildlife, aesthetics, and environmental quality, however, are expressed in terms of the impact on the general public because landowners cannot capture all their value.

---

[1]*A detailed handbook is available from the authors that describes step by step field data collection and office calculation procedures.*

Timber Values

Two methods, the current value and the present net value approach, were considered for appraising fire effects on timber. The present net value approach is the most theoretically correct; but it presents practical difficulties because it requires the prediction of future harvest dates, yields, and prices as well as selection of an appropriate interest rate. In Wisconsin it would also require an increase in field measurements because only diameter class and volume by timber type are presently being recorded, and site index and volume by species are also needed to estimate present net value. Current value, although theoretically less correct than present net value, is simpler to apply because it eliminates the problems associated with predicting harvest date, prices, and yields. If severance tax values are used, field measurements are greatly reduced. The current value method, however, assumes no value for immature timber.

For these reasons we employed a combination of the current value (based on Wisconsin severance tax values) and the present net value methods. Merchantable timber is appraised at current value. The present net value is used for immature timber, but the harvest date is assumed to be the date at which the stand first becomes merchantable rather than the "optimum" rotation age. Using this shorter period reduces both prediction problems and the importance of the choice of discount rate. Salvage value is not considered because it is difficult to determine at the time of the fire, and fire damaged timber is not usually merchantable in Wisconsin.

Losses of merchantable timber are assessed using the following equation:

$$\text{loss} = \begin{matrix}\text{average}\\ \text{volume}\\ \text{per acre}\end{matrix} \times \begin{matrix}\text{average}\\ \text{price by}\\ \text{district}\end{matrix} \times \begin{matrix}\text{predicted}\\ \text{mortality}\end{matrix} \times \begin{matrix}\text{acres}\\ \text{burned.}\end{matrix}$$

The procedure for immature timber is the same except that average volume is predicted rather than measured and a 6 percent discount rate is applied. Christmas trees are an exception and are valued by tree rather than by volume.

Regeneration losses and replacement values are calculated only for natural red pine, jack pine less than 7 years old, and white cedar stands with a hardwood understory or with more than 30 percent of the stand in other conifers if more than half of the cedar are killed. All other timber types and conditions will regenerate naturally to the prefire timber type.

The prices used are those calculated annually for timber types by the Wisconsin DNR timber management staff. They are based on the average volume of each species in a particular type for each district. Local stumpage prices for a single species are used only in pure stands, such as plantations.

Predicting tree mortality shortly after a fire is essential to determine timber effects and other value components. Data from Methven (1971) and Loomis (1973), and data collected by the Wisconsin DNR in 1979 were used to develop two linear regression lines for conifers based on percent of crown scorched (fig. 1), and two for hardwoods based on the height of bark scorched (fig. 2). The equations for conifers are:

for $x \leq 57$; $y = 1.386 + 0.401x$; $R^2 =$ [2]0.66
for $x > 57$; $y = -75.817 + 1.758x$; $R^2 =$ [2]0.73

where y is estimated mortality (percent) and x is the percent of crown scorched. The equations for hardwoods are:

for trees $\leq$ 5 inches d.b.h.; $y = 49.248 + 4.911x$; $R^2 =$ [2]0.69
for trees $>$ 5 inches d.b.h.; $y = 11.861 + 5.070x$; $R^2 =$ [2]0.75

where y is estimated mortality (percent) and x is the height of bark scorched.

Wildlife Values

Appraising the physical effects of fire on wildlife is difficult and translating these into economic terms is even more complex. An extremely broad range of possible approaches exists (Shaw and Zube 1980), but no comprehensive and universally accepted system has been developed. Most of the methods considered for Wisconsin attempt to determine the willingness of consumers to buy or sell wildlife-related opportunities. Techniques used to do this include the direct survey, travel cost, market alternative, consumer surplus, opportunity cost, and gross expenditure. The gross expenditure approach was selected for Wisconsin because of the availability of data showing the amount of game harvested by county (Wisconsin DNR n.d.), expenditures and days spent hunting various species (National Analysts 1975), and changes in game populations following fires of different sizes (e.g., McCaffery and Creed 1969). While recognizing that wildlife is valuable for many noneconomic reasons, we assumed that most of the economic value is associated with outdoor recreation,

[2]*For grouped data.*

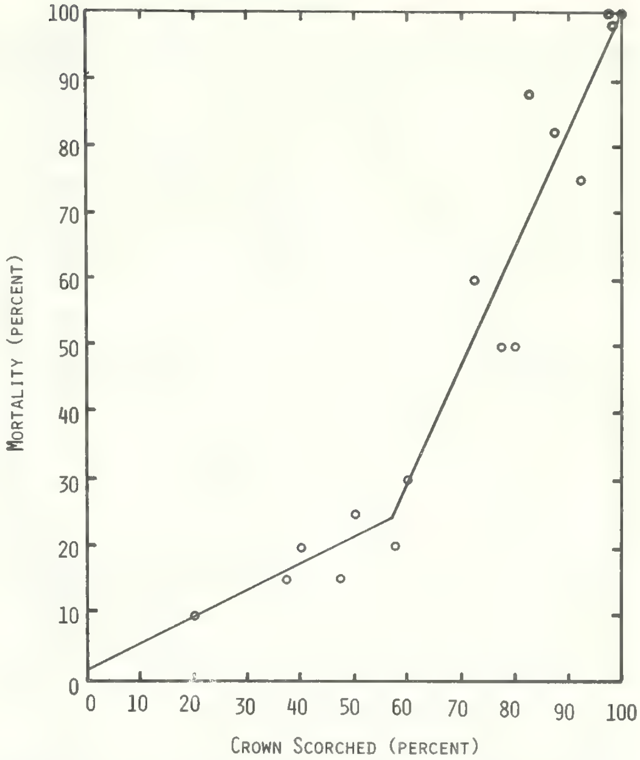

Figure 1.—*Observed conifer mortality and regression line.*

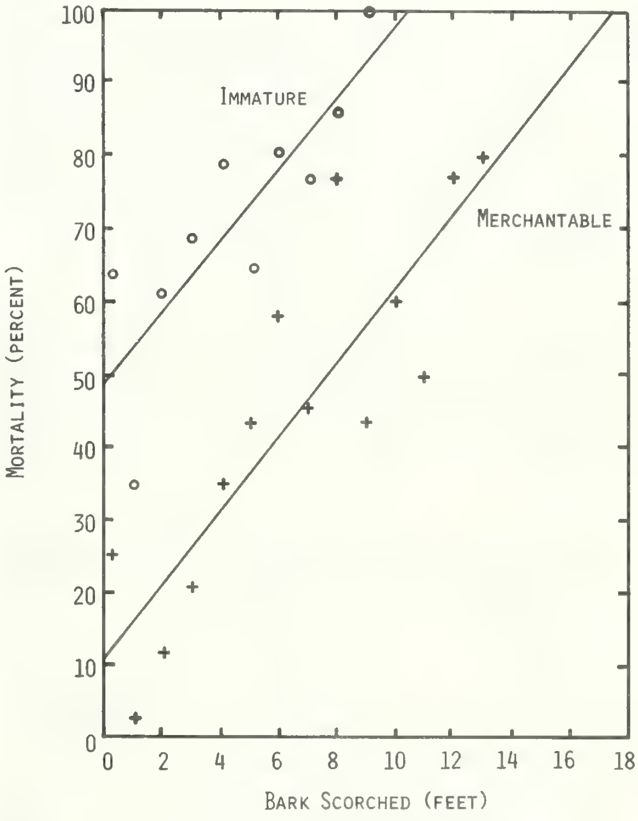

Figure 2.—*Observed hardwood mortality and regression line.*

primarily hunting for game species. This value can be estimated using available figures for the average expenditure per day of hunting each species. A similar figure for expenditures to observe wildlife, including nongame species, is also available. However, pilot tests of the system showed that the observation values affected by fire were negligible and no further attempt was made to estimate them. Fire effects on fish are also assumed to be negligible.

If a fire occurs in a cover type important to deer, small game, or waterfowl, the economic loss and/or benefit are estimated using the basic formula:

$$\text{loss or benefit} = \text{use change} \times \text{wildlife loss or benefit factor.}$$

Use change is a measure of the effective area burned. It is a function of tree mortality and the size of the burned area. Wildlife loss and benefit factors were developed for each county in Wisconsin (table 1). Each factor is the product of the success index for a particular species and county, the average expenditure for a day spent hunting that species, and the full effect of the fire on game populations. The full effect is the change in game population expected if all trees were killed. Generally, the success index is a ratio of use per acre in a county to the average use per acre in Wisconsin. Thus, a success index of one indicates average use, while a two indicates twice the average use. Estimates of the 1980 value of a user day based on hunter expenditures (National Analysts 1975) were $31.82 for deer hunters, $9.61 for small game hunters, and $17.23 for waterfowl hunters.

Benefits to white-tailed deer (in the form of increased browse) accrue when fires occur in white birch and northern hardwood stands or in jack pine and red pine plantations. Losses occur when the fire is in a spruce-fir, black spruce, tamarack, or cedar type.

Fire effects on small game species (rabbit, pheasant, grouse) are primarily beneficial and result from fires in black spruce, white birch, aspen, jack pine, and open fields.

Waterfowl benefit from fires in marshes or open fields within 0.25 miles of water but are harmed if the fire occurs during the nesting season between April 15 and July 31.

Recreation Values

The recreation element includes the effects of wildfires on developed recreation sites and aesthetics. For recreation on developed sites, the same willingness to pay approaches evaluated in the wildlife section were considered and the gross expenditures method was again adopted. The effect of wildfire on developed recreation sites is based on an estimate of the number of visitor groups that would have used the site during the remainder of the season (from time of fire to December 31) and the value per visitor group day for various recreational activities. Determining possible substitution impacts was considered too complex and subjective for practical application. Based on a survey of expenditures in 1969 (Wisconsin DNR 1969) and inflated to 1980 dollars, the values used were:

Sightseeing	–$29.74
Camping	– 28.30
Fishing	– 26.43
Picnicking	– 21.64
Boating	– 17.86
Hiking	– 17.14
Swimming	– 12.06

Although no attempt was made to put dollar values on the effects of wildfire on aesthetics, the Wisconsin system provides a consistent procedure to determine the relative impact. Variables influencing the aesthetic effect are the size of the area burned, the aesthetic importance of the area, and the intensity and duration of the effect. Five recreation use classes were identified to rate the relative aesthetic importance of the burned area.

One criterion for selecting the appropriate use class is the type of road from which the burned site can be seen. The highest category is a site visible from a four lane highway while the lowest category is a site that cannot be seen from any road. A second criterion is the general recreational use of an area from which the fire site is visible. Lakes with public access and developed sites such as campgrounds and picnic areas rate the highest category. The lowest category is used for burned areas that cannot be seen from any road, trail, lake, or stream.

The intensity and duration of the fires' effect is measured by determining tree mortality using four arbitrary categories. Aesthetic effects are rated as extreme, very heavy, heavy, moderate, light, or negligible.

Table 1.—*Wildlife loss and benefit factors*

(In dollars/acre)

Region and County	Deer[1] Benefit	Deer[1] Loss	Small game[2] SB,BW	Small game[2] A,PJ	Small game[2] Open field	Waterfowl[3] Benefit	Waterfowl[3] Loss
Lake Michigan							
Brown	19.60	11.37	12.49	14.02		6.69	1.11
Calumet	58.80	34.12	12.49	14.02		8.97	1.80
Door	91.87	63.98	1.02	1.99		1.04	.21
Florence	58.80	34.12	.00	1.99		1.04	.21
Kewaunee	91.87	63.98	6.64	16.94		3.60	.67
Manitowac	91.87	63.98	6.64	10.34		6.69	1.11
Marinette	143.34	83.17	6.64	6.94		1.04	.21
Menominee	143.34	83.17	1.02	1.98		3.60	.67
Oconto	143.34	83.17	.00	1.98		3.60	.67
Outagamie	143.34	83.17	12.49	14.02	2.76	3.60	.67
Shawano	143.34	83.17	2.60	6.94		3.60	.67
Waupaca	308.71	214.38	6.64	10.34		3.60	.67
Waushara	308.71	214.38	2.60	6.94		3.60	.67
Winnebago	58.80	34.12	3.79	14.02	12.21	15.52	3.10
Southern							
Columbia	308.71	214.38	2.60	1.98	12.21	15.52	3.10
Dane	58.80	34.12	6.64	10.34	6.99	5.57	1.11
Dodge	19.60	11.37	12.49	14.02	24.67	36.76	7.35
Fond du Lac	58.80	34.12	12.49	14.02	24.67	36.76	7.35
Grant	19.60	11.37	1.02	1.98		3.60	.67
Green	19.60	11.37	12.49	14.02	24.67	1.04	.21
Green Lake	308.71	214.38	6.64	6.94	24.67	36.76	7.35
Iowa	214.39	124.41	1.02	4.35	2.76	3.60	.67
Jefferson	19.60	11.37	6.64	6.94	12.21	36.76	7.38
Lafayette	19.60	11.37	12.49	14.02	12.21	1.04	.21
Marquette	308.71	214.38	1.02	1.98		15.52	3.10
Richland	143.34	83.17	6.64	10.34		1.04	.21
Rock	19.60	11.37	25.47	29.08	24.67	5.57	1.11
Sauk	214.39	124.41	6.64	6.94		3.60	.67
Southeast							
Kenosha	19.60	11.37	25.47	29.08	6.99	5.57	1.11
Ozaukee	19.60	11.37	2.60	1.98	24.67	5.57	1.11
Racine	19.60	11.37	25.47	29.08	6.99	8.97	1.80
Sheboygan	58.80	34.12	6.64	10.34	24.67	5.57	1.11
Walworth	19.60	11.37	25.47	29.08	6.99	5.57	1.11
Washington	58.80	34.12	6.64	4.40	12.21	3.60	.67
Waukesha	19.60	11.37	25.47	29.08	12.21	3.60	.67
Northwest							
Ashland	58.80	34.12	.00	1.98		1.04	.21
Barron	58.80	34.12	1.02	4.35		3.60	.67
Bayfield	91.87	63.98	.00	1.98		1.04	.21
Burnett	143.12	83.17	.00	4.35		5.57	1.11
Douglas	19.60	11.37	.00	4.35		1.04	.21
Iron	19.60	11.37	.00	1.98		1.04	.21
Polk	143.12	83.17	1.02	6.94		3.60	.67
Price	91.87	63.98	.00	1.98		1.04	.21
Rusk	91.87	63.98	1.02	1.98		1.04	.21
Sawyer	58.80	34.12	.00	4.35		1.04	.21
Taylor	58.80	34.12	.00	1.98		1.04	.21
Washburn	91.87	63.98	.00	1.98		1.04	.21

(Table 1 continued on next page)

(Table 1 continued)

Region and County	Deer[1] Benefit	Deer[1] Loss	Small game[2] SB,BW	Small game[2] A,PJ	Small game[2] Open field	Waterfowl[3] Benefit	Waterfowl[3] Loss
West Central							
Buffalo	308.71	214.38	1.02	1.98		8.97	1.80
Chippewa	58.80	34.12	1.02	4.35		1.04	.21
Clark	143.12	83.17	1.02	1.98		1.04	.21
Crawford	143.12	83.17	1.02	6.94		15.52	3.10
Dunn	58.80	34.12	1.02	4.35		3.60	.67
Eau Claire	143.12	83.17	1.02	4.35		1.04	.21
Jackson	308.71	214.38	2.60	14.02		1.04	.21
La Crosse	143.12	83.17	2.60	6.94		15.52	3.10
Monroe	143.12	83.17	1.02	4.35		1.04	.21
Pepin	143.12	83.17	2.60	4.35		5.57	1.11
Pierce	58.80	34.12	1.02	4.35		3.60	.67
St. Croix	19.60	11.37	1.02	4.35	6.99	3.60	.67
Trempealeau	214.39	124.41	1.02	6.94		1.04	.21
Vernon	143.12	83.17	2.60	6.94		8.97	1.80
North Central							
Adams	308.71	214.38	6.64	10.34		3.60	.67
Forest	58.80	34.12	.00	10.34		1.04	.21
Juneau	214.39	124.41	1.02	4.35		8.97	1.80
Langlade	91.87	63.98	1.02	1.98		1.04	.21
Lincoln	143.12	83.17	1.02	10.34		1.04	.21
Marathon	143.12	83.17	6.64	10.34		3.60	.67
Oneida	143.12	83.17	.00	4.35		3.60	.67
Portage	214.39	124.41	2.60	10.34		3.60	.67
Vilas	91.87	63.98	.00	6.94		3.60	.67
Wood	308.71	214.38	2.60	6.94		5.57	1.11

[1]Benefits to deer result when fires occur in white birch and northern hardwood stands or in jack pine or red pine plantations. Losses occur when fire is in a spruce-fir, black spruce, tamarack, or cedar type.

[2]Fire effects on small game are beneficial and result from fires in black spruce, white birch, aspen, jack pine, and open fields.

[3]Waterfowl benefit from fires in marshes or open fields within 0.25 miles of water, and losses result if the fire occurs during the nesting season between April 15 and July 31.

Ornamental Tree Values

Many Wisconsin wildfires occur near residences or developed recreation sites where they damage ornamental trees. Selling timber is not the reason for having ornamentals, and it is not appropriate to appraise them on the basis of timber values. Theoretically, the most correct appraisal technique is to estimate property value changes due to ornamental tree losses. However, this would require accurate property appraisals of values prior to and following fires that are beyond the capabilities of field personnel. The method selected assumes that an ornamental tree is lost if the estimated probability of mortality (determined from the mortality graphs) is 50 percent or greater. Small trees and shrubs are appraised at nursery replacement value. The value of each large tree or group of similar trees is estimated using the following formula:

value = base value x species factor x condition factor x location factor.

This formula was developed by the International Shade Tree Conference in 1969 (Michigan Forestry and Park Association 1978). The base value used in Wisconsin is $16.56 per square inch. This is obtained from $9.00 per square inch determined at the International Shade Tree Conference in 1969, inflated to 1980 dollars. The species factors, also developed at the conference, assign each species a factor of 0.25, 0.50, 0.75, or 1.0 according to its desirability as an ornamental. The condition factor is a relative rating, between zero and one, of the prefire health, form, and vigor of the affected tree. The location factor is an assessment of the importance of the ornamental tree in the landscape, ranging from one for a single specimen on a key site to near zero for one of a group of trees at the forest edge of a developed site. All trees must be visible from and within 100 yards of

a lake, home, or developed recreation site to be considered ornamentals.

Environmental Values

Information available in Wisconsin indicates that water quality and soil stability are rarely significantly affected by a single fire. Air quality, however, is affected by smoke, and although no dollar value was assigned, a method to estimate the relative importance of smoke effects on air quality is employed. The method requires determining atmospheric stability (stable or unstable), a smoke index, and a population use class. The smoke index is based both on the size of the fire and the duration of the smoke. Thus a small but long-burning peat fire might produce a higher smoke index than a large grass fire. Five population use classes were identified to rate the importance of use areas affected by the smoke. The classes generally depend on the size of the city or town in which the smoke can be detected, although highway size and recreation use can also influence the classification. The effects are rated as extreme, severe, heavy, moderate, light, or negligible.

Crop Values

The procedure for evaluating the effects of fire on crops and forage is similar to that for timber but simplified by several factors. Most crops are harvested annually, thus eliminating the problem of discounting future values. County agents are generally able to estimate yields and prices. The problem of predicting mortality is also eliminated because crops rarely survive a wildfire. With the new Wisconsin system the loss of a crop is simply the net value of the expected yield except in the unlikely event that the crop can be replanted. If the burned crop can be replanted in the current year, the loss is the sum of the replanting cost and the value of the reduction in the expected yield (the replanted crop would probably have a reduced yield due to a shorter growing season). In either case the following equation can be used:

$$\begin{matrix}\text{crop}\\\text{loss}\end{matrix} = \begin{matrix}\text{replanting}\\\text{cost}\end{matrix} \times \begin{matrix}\text{acres}\\\text{burned}\end{matrix} + \begin{matrix}\text{yield}\\\text{loss}\end{matrix} \times \text{price} \times \begin{matrix}\text{acres}\\\text{burned.}\end{matrix}$$

If a crop cannot be replanted in the current year, the replanting cost is zero.

Equipment and Improvement Values

The method used to appraise damage to equipment and improvements is to estimate the cost to replace the items that are completely destroyed or to restore a damaged item to its prefire condition. In some cases, this will be the additional maintenance required to restore that condition, for example, repainting a barn blackened by smoke.

The field procedures require determination of items that require repair or replacement and an estimate of the prefire condition. The cost of the repair or replacement is determined in the office. Blue books, contractors, and equipment dealers should be consulted.

IMPLEMENTING THE SYSTEM

Pilot Testing

In 1980, a group of Wisconsin foresters was selected and trained to use and test the new system. The selection was based on the need to include the entire range of timber types and fire experience in Wisconsin. The training took approximately 2 days and included practice exercises for several hypothetical fires. Each participant was instructed to appraise each fire in his district using both the old and the new system. Each was asked to critically evaluate the system and be prepared to discuss the need for changes and improvements. Revisions were made and testing continued during the 1981 fire season. Final revisions were made and training conducted to implement the system Statewide prior to the 1982 fire season.

The cooperative development of the new Wisconsin appraisal system attempted to strike a balance between a theoretically correct system and one that is practical and easy to use. Testing by field foresters identified practical problems that required revisions and also resulted in streamlining the reporting forms and the instruction guidebook. Most were pleased with the new system and had little difficulty applying it.

SUMMARY

The new system provides a consistent method for appraising the full range of fire-related resource effects. It represents a step forward in the evolution toward complete and theoretically correct State systems and is flexible enough to accommodate changes as more current information becomes available and

as general tables, based on applications of more complex systems over a period of years, are developed for easy use in the field. Although no attempt is made to put dollar figures on some nonmarket values, a well-defined procedure is provided to estimate the relative impact of fire on these resources. Although certain of the inputs required are specific to Wisconsin, such as hunter success indices and timber types or prices, similar data for many other Northeastern States are probably available and the basic format should be generally useful.

The items listed below should be updated periodically or as new information becomes available.

1. **Timber Prices**—New prices can be obtained annually from Wisconsin DNR timber management personnel.

2. **Wildlife Success Indices**—These should be reviewed and updated at two to five year intervals. If the second update shows only minor changes are occurring, subsequent updatings may be unnecessary.

3. **Wildlife Values**—When no new data are available, the value per hunter day for each species should be adjusted annually for inflation using the consumer price index. The adjustment should be in early spring after the consumer price index becomes available but before the fire season begins. New values should be used as they become available in the National Surveys of Hunting, Fishing and Wildlife Associated Recreation published periodically by the U.S. Fish and Wildlife Service.

4. **Ornamental Tree Values**—Values should be adjusted annually for inflation.

5. **Recreation Values**—Values per visitor day for each type of use should be adjusted annually for inflation until new information becomes available.

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A fire effects appraisal system for Wisconsin. Gen. Tech. Rep. NC-90. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 8 p.

Describes a new wildfire effects appraisal system developed for Wisconsin.

KEY WORDS: Fire management, economics, fire damage, fire benefits, valuation procedure.

United States
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North Central
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General Technical
Report NC-91

Intensive Plantation Culture: 12 Years Research

FOREWORD

"Intensive culture" as used in this report is defined as the application of several cultural practices to the establishment and management of plantations with the objective of increasing the quantity and quality of wood produced. The program under review is officially termed the "Research and Development Program: Maximum yield of wood and energy from intensively cultured plantations". It superceded an earlier multiproject program (MPP-II). These programs formed an organizational structure for a multidisciplinary research approach including genetics, physiology, silviculture, soils, entomology, pathology, engineering, utilization, and economics all directed towards a common goal of developing an entirely new silvicultural management system. The research mission of the program is to develop the most biologically efficient and economically feasible method of producing maximum commercial wood per acre by means of a systems approach involving the unified effort of several disciplines. Research was predominantly with hybrid poplar although other species were included throughout the program. This report contains the papers presented at the annual review at the end of the 5-year chartered Research and Development Program. The papers collectively provide a state-of-the-art of intensive culture research and will provide a base for joint planning by managers and researchers for the period ahead.

Each contributor submitted camera copy and is responsible for the accuracy and style of his or her paper.

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INTENSIVE PLANTATION CULTURE: 12 YEARS RESEARCH

Edward A. Hansen, Compiler

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CONTENTS

THE PRACTICE AND PHYSIOLOGICAL BASIS OF COLLECTING, STORING AND PLANTING POPULUS HARDWOOD CUTTINGS

Anne S. Fege[1]

Abstract.--Producing healthy hardwood cuttings for Populus plantation establishment requires attention to the management of clonal nurseries, timely collection of cuttings, adequate grading of cuttings, storage temperature and conditions, preplanting treatments, and planting operations. Recommended nursery practices are outlined, along with their grounding in such biological factors as stem anatomy, moisture content, induction of dormancy, availability of carbohydrate reserves, and freedom from insects and pests.

Hybrid Populus plantations can be successfully established with hardwood cuttings of selected, fast-growing clones. Nursery managers and foresters in Europe and North America have a wealth of experience and knowledge about collecting, storing and planting hardwood cuttings, yet our understanding of the biological reasons for these practices is not nearly as thorough. However, physiological studies have offered many generalizations about cutting production that have further refined nursery practices. The empirical knowledge of each of the practices involved in producing healthy cuttings and the physiological bases for these practices are summarized in this paper, drawn principally from the literature on Populus and on our experiences at the Forestry Sciences Laboratory in Rhinelander, Wisconsin.

The recommended production practices are a sequence of activities, beginning with the establishment of clonal nurseries, as represented in Figure 1. All of these practices are directed toward the ultimate objective of producing trees that have high survival rates and maximum vigor and height growth, particularly during the first growing season. With early rapid growth, the time is reduced that costly weed control treatments are required and that terminal shoots are out of reach of browsing deer.

The findings reviewed in this paper are limited to hardwood cuttings of Populus clones that root easily from hardwood cuttings. Because of their stem anatomy, roots begin to emerge from the bark of these cuttings within several days of

Figure 1.--Required practices and factors affecting the production and establishment of healthy cuttings.

CLONAL NURSERIES →	COLLECTION →	CUTTING SELECTION →	STORAGE →	PRE-PLANT TREATMENTS →	PLANTING OPERATIONS →	HEALTHY PLANTATIONS
Establishment Nutrition of Parent Plant Pest Management	Time of Year Equipment	Diameter Position Absence of Disease or Wounds	Duration Temperature Conditions Moisture Pathogens	Duration Soaking in Water Fungicide Dips	Site Preparation Soil Moisture Planting Equipment Weed Control	

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soaking in water. One-year-old stems and some older wood of poplars (Populus sections Aigieros and Tacahamaca), willows and other species have performed root primordia, which generally originate in ray tissue of the secondary phloem (Braun 1963, Haissig 1974, Hartmann and Kester 1975, Swingle 1929, and Smith and Wareing 1972a). These adventitious roots only need to increase in length and size. Wound roots may also be produced from the base of the cutting, sometimes following callus formation. These wound roots are relatively unimportant in species with preformed root primordia, but become the adventitious roots in species and plant material that lack preformed root initials. Cuttings of the Leuce section of Populus have few preformed primordia, and are much more difficult to root (Farrar 1977, FAO 1979). Many Populus clones can also be propagated from roots, suckers, or grafts (FAO 1979, Hartmann and Kester 1975, and Williams and Hanks 1976). Softwood (or greenwood or tip) cuttings taken from non-dormant rapidly-growing shoots have received most of the attention in empirical and physiological studies of cuttings. Research efforts on softwood cuttings, and on hardwood cuttings of species or plant material that lacks preformed root primordia, have been directed toward altering environmental conditions and applying chemicals (usually hormones such as auxin) that promote root initiation.

Clonal Nursery Management

Managers who plan to establish large plantations or who want to control the quality and availability of hardwood cuttings should install and maintain their own clonal nurseries. Each hectare of Populus plantations established at spacings of 1 m^2/tree requires 10,000 cuttings (4,000/acre), and 2500 cuttings for spacings of 4 m^2/tree (1,000/acre), so large numbers of cuttings must be produced and handled.

Generally, 4 to 10 whips are produced from each rootstock, and 5 to 8 20-cm cuttings can be obtained from each whip (depending on the clone and shoot condition), thus each healthy rootstock could yield from 20 to 80 cuttings annually. A clonal nursery established with 1 or 0.5 m between trees within rows and 1 m between rows allows plenty of room for tractors and equipment used for harvest of cuttings (Hansen, Moore, Netzer, Ostry, Phipps and Zavikovski 1982). About 10,000 rootstocks could be maintained per hectare, and about 200,000 cuttings produced per hectare annually. Additional acreage must be allotted to roads and irrigation lanes, and some consideration given to the failure of rootstocks to resprout. For Populus plantations established in the southern United States, McKnight (1970) recommended that clonal nurseries be established with 0.3 m spacings within rows and 1 m between rows, to maximize production of unbranched whips. Many clonal nurseries are also established at wider spacings, typically 1 m between trees within rows and 3 m between rows, which facilitates cultivation and increases the number of whips produced per rootstock. Spacings of up to 3 m between rows reduce incidence of some diseases such as Septoria canker and allow sanitation practices such as disposal of infected residues and soil cultivation to be undertaken more easily (Hansen et al. 1982).

Maintenance of healthy nursery plants is essential, since cutting vigor has been related to nutrition of the parent shoot (FAO 1979, Hartmann and Kester 1975). Clonal nurseries at Harshaw Experimental Farm (10 miles west of the Forestry Sciences Laboratory, Rhinelander, Wisconsin) have been established from disease-free hardwood cuttings, fertilized, irrigated, and maintained weed-free by mechanical cultivation and herbicides. McKnight (1970) recommended that a well-drained site be chosen, and that nursery beds be fumigated if cottonwood had been grown there previously. The Food and Agriculture Organization publication Poplars and Willows (1979) recommends that nurseries be established on fertile, well-drained soils; fertilized; maintained free of weeds; and protected against insects and disease. Clones which are particularly susceptible to diseases should be removed from the clonal nursery.

After 1 or 2 years, the planted trees are cut back to within 15 cm of the ground, and the resultant coppice growth harvested annually thereafter for cuttings. Rootstocks can normally be maintained for 4 to 8 years until sprouting vigor is markedly reduced. Although the author knows of no study on the longevity of Populus nursery rootstocks, there have been some studies on the effect of season of harvest and cutting method on coppice regeneration of plantations. DeBell and Alford (1972) reported that sprouting vigor was greatest when harvests were made during the dormant season, as would be the case for cutting production, and that cutting height and angle had no effect on initial sprouting of stumps established from P. deltoides cuttings. Hansen et al. (1982) recommend that stumps be cut 15-20 cm above the ground each year. Phipps (personal communication) offered the observation that some sprouts grow nearly horizontal to the ground when stumps are cut nearly at ground level. Lust and Mohammady (1973) suggested that rupture of the bark and bursting of the stool be avoided, that the cutting surface be as close to the soil as possible so that some shoots develop their own root systems, and that the cut be smooth and angled so that water can run off. Crist and Mattson[2/] found that stump mortality was

[2/] Crist, J. B., J. A. Mattson and S. A. Winsauer. 1983. Effect of severing method and stump height on coppice growth. This publication.

significantly greater for Populus 'Tristis #1' trees severed in February with a shearing head than for stumps sawn with a chain saw, with some mortality caused by shearing head's damaged to adjacent stumps.

Collection of Cuttings

Collecting and sorting cuttings is still labor-intensive, and there are many opportunities for reducing labor requirements and costs of processing cuttings. At the Harshaw Experimental Farm, a side-mount sickle bar mower is used, that has a sharp bar and is in good operating condition, to minimize ragged cuts, splitting, and other damage to stumps. The mower is followed by a tractor-drawn wagon, onto which two workers load the harvested whips. Harvest systems are being developed that will cut whips, tie them in bundles and load them onto wagons for transport to the processing area (Hansen et al. 1982).

Hardwood cuttings must be collected after shoots achieve some degree of dormancy and before the end of dormancy is reached in the spring. Most commercial nurseries collect hardwood cuttings from December to early March, as displayed in Table 1.

In regions where snow cover and cold temperatures hamper the ability of field crews to collect cuttings in mid-winter, cuttings may be collected in late fall. In the fall of 1980, hardwood cuttings of 7 hybrid Populus clones (whose parentage is listed in Table 2) were collected monthly from the Harshaw Experimental Farm from mid-September to mid-December. Cuttings were stored over the winter at temperatures from 2 to -20°C, and planted in mid-May (Fege and Phipps 1982). A similar study was conducted the following year, with cuttings of 3 clones collected in mid-October and mid-December, stored at 3 temperatures, and planted in May. As shown in Table 3, survival was poor for all cuttings collected in September. Survival and height of cuttings collected in mid-October were not significantly different from cuttings collected in November or December for any of the clones, with the exception of clone group 5262 collected in mid-October and stored at -20°. Bud set was 2 weeks later for clone group 5262 than clone group 5334 or clone 5260, and this suggests that plant material of clones 5262, 5263, 5272, and 5377 was not sufficiently hardened by mid-October to withstand -20° temperatures. In the 1981-82 study, overall height growth was much less for all treatments and clones because of lower temperatures in June and poor weed control in the plots, but survival patterns were similar. Whereas overall survival of clone 5260 was poor in the 1980-81 study, its performance paralleled that of clone 5334 in 1981-82.

Some studies of effects of collection date must be interpreted cautiously, since cuttings were planted in greenhouses immediately after they were taken from the field. Field managers would not be able to plant cuttings in January or February. Yet, these studies offer additional insight into the physiological conditions of parent material during the winter. Allen and McComb (1956) found greater survival and rooting of cuttings collected in March and planted immediately, than those collected and planted in November or December. Farmer (1966) found that Populus deltoides cuttings collected in Mississippi in early February rooted better than those cut in December, January or early March, when planted immediately after collection. Phipps and Netzer (1981) collected cuttings of 4 clones monthly from November to March and planted them immediately in a greenhouse, and found that rooting and bud break occurred more rapidly in the later-collected cuttings, and that the lowest rate of rooting was for cuttings collected in November. Cuttings collected in November and stored at 2.8°C for 5 months had the same rate of rooting as March-collected cuttings, suggesting that proper storage may permit earlier collection of cuttings with no loss of rooting ability.

Some degree of dormancy must be achieved before cuttings are harvested. Physiological changes accompanying the process of dormancy induction include cessation of growth, increase in stored reserves, development of cold hardiness, and leaf fall. Our studies have shown differences in carbohydrate content in dormant Populus shoots throughout the winter.[3/] Starch content is greatest in early fall, and declines progressively to minimum levels in December through early March. Content of total sugars increased from September to December, maintaining high levels until early March. Although a direct relation between carbohydrate content and field performance has not been established, we assume that these carbohydrate reserves provide the energy for early growth and emergence of functioning roots.

Selection for Cutting Size and Position

Entire whips are generally sawn into cuttings of about 20 cm in length, then sorted and bundled. After entire whips are brought in from the field, branches are clipped from the mainstem and discarded, then 4 to 6 whips are held together and sawed into 20-cm lengths with a band saw. The small-diameter shoot tip and any portion of the stem base which is less than 20 cm in length is

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3/ Fege, A. S. and G. N. Brown. 1983. Carbohydrate distribution in dormant Populus shoots and hardwood cuttings. In preparation for Forest Science.

Table 1. Commercial nursery practices for collection and storage of *Populus* hardwood cuttings.[1/]

	Collection Date	Storage Conditions	Planting or Shipping Date
1.	January and February	Stored as cuttings, covered with moist peat moss, at 1 to 2°C, or uninsulated barn as low as -7°C.	May
2.	Late winter, while still dormant	(Planted as soon as possible; kept in cellar until planting.)	
3.	Mid-December through February	Stored as cuttings in wet peat moss or shingletoe in wooden crates lined with plastic (10 bundles of 100 cuttings/bundle in each crate) at -3 to 0°C.	Late April to June
4.	February and March	Bundles of 15-cm cuttings dipped in Chlorox, put in wet peat/sand mixture, at 1 to 2°C in 100 percent humidity room.[2/]	After last frost (May)
5.	January and February	Bundles of 150 15-cm cuttings dipped in Captan-Benlate solution, and 6 to 8 bundles stored in 30-gallon plastic trash bags at -1°C.	May
6.	Mid-December to late February	Stored as cuttings in plastic bags held in cardboard boxes at -2°C (bud break occurs in cuttings stored at 0 and 2°C).	Late March to late May
7.	November and December	Stored as bundles of 12-cm cuttings placed in wooden flats with basal ends in moist sphagnum moss. Held at 10 to 15°C for 2 weeks to initiate callus formation and roots, then stored at 1°C.	Mid-May
8.	December	Stored as entire whips in humidity-controlled room, at -2°C until March. Whips sawed into cuttings, bundles dipped in fungicide and stored at 1°C in mulch until planting.	Late April
9.	December	Whips harvested in December, sawed into cuttings in January, and stored in plastic bags below 0°C.	April and May
10.	December and January	Stored as 32-cm cuttings in plastic bags in unheated barn. In late February, cuttings moved to cold storage at -1°C.	May and June
11.	During dormancy[3/]	Stored as cuttings at -2 to 0°C, bundles set in 5-7 cm of moist sand, covered with wet burlap. If cuttings taken immediately before planting, cuttings are held in aerated ponds for 3 days or more.	December to early March (southern U.S.)

[1/] Nurseries located in Maryland, Michigan, Minnesota, Montana, Ohio and Pennsylvania.

[2/] Mention of commercial products does not constitute endorsement by the University of Minnesota or the U.S. Department of Agriculture.

[3/] From McKnight (1970).

Table 2. Parentage of hybrid Populus clones.

Original Number	North Central Number	Parentage[1/]
---	5260	(P. tristis x P. balsamifera) 'Tristis #1'.
NE-387	5262	P. 'Candicans' x (P. x berolinensis)
NE-386	5263	P. 'Candicans' x (P. x berolinensis)
NE-1	5272	(P. nigra x P. laurifolia) 'Strathglass'
NE-252	5334	P. deltoides var. angulata x P. trichocarpa
---	5377	P. x euramericana 'Wisconsin #5'
---	9922	Populus spp.

1/ From Hansen et al. (1982). Names according to Dr. Donald Dickmann, Department of Forestry, Michigan State University, East Lansing, MI. 48824.

Table 3. Field performance of hardwood Populus cuttings, by date of collection and storage temperature.

	Percent Survival				Height of Surviving Trees (cm)[1/]			
Date of Collection	2	-3	-10	-20	2	-3	-10	-20
1980-1981 Study								
5262 group[2/]								
September	76	0	1	0	87	-	-	-
October	86	92	94	14	111	107	115	-
November	100	93	93	97	111	106	113	111
December	95	96	95	96	97	114	111	115
5334 group[3/]								
September	77	7	0	0	78	-	-	-
October	87	90	88	78	101	97	103	82
November	72	62	53	78	77	65	75	80
December	97	90	82	88	85	108	95	92
Clone 5260								
September	7	10	23	0	-	-	-	-
October	30	3	100	93	-	-	61	74
November	17	7	93	97	-	-	68	59
December	53	37	97	63	-	-	71	49
1981-1982 Study[4/]								
Clone 5262								
October	65	70	20	-	33	45	-	-
December	82	85	75	-	57	45	42	-
Clone 5334								
October	92	88	75	-	35	36	25	-
December	98	92	82	-	45	37	35	-
Clone 5260								
October	92	80	100	-	21	26	36	-
December	90	86	80	-	20	22	29	-

1/ Generally for treatments with greater than 60 percent survival.

2/ Clones 5262, 5263, 5272 and 5377.

3/ Clones 5334 and 9922.

4/ Cuttings held at 2, -3 and -10°C in 1981-1982 study.

discarded. At most nurseries and research stations, teams of workers sort cuttings manually. Careful labeling of the clone number for each batch of cuttings is essential. At Harshaw Experimental Farm, cuttings that do not meet the following grading standards are discarded: (1) diameter greater than 0.95 cm, (2) no evidence of mechanical damage such as stripped bark, split or crushed ends, or broken or missing buds in the top third of the cutting; (3) no signs of disease or insect infestation such as fruiting bodies, galts, lesions, eggs, or borers; and (4) green inner bark and no dessicated or shrivelled outer bark. The acceptable minimum and maximum diameter values vary by clone and generally are set to exclude the terminal cutting and cuttings made from the upper portions of small-diameter whips. All cuttings should be oriented in the same direction, to eliminate the need for such orientation by the planting crew.

Two well-accepted generalizations may be made about cuttings: larger cuttings perform better than smaller cuttings, and cuttings taken from the shoot terminus root poorly. However, it is difficult to separate the effects of cutting diameter, cutting length, and position of the cutting within the parent shoot. Larger-diameter cuttings had higher survival rates and produced taller shoots and shoots with greater dry weight, in studies with 20-cm cuttings in Michigan and Wisconsin (Dickmann, Phipps and Netzer 1980). Clonal response differed greatly, with shoot height differences of 14 percent between largest- and smallest-diameter cuttings for one clone, and 250 percent for another clone. For 3 of the clones tested, survival was 20 to 40 percent less for cuttings with diameters of less than 6 mm, suggesting that this may be a minimum diameter for cuttings used in field plantings of many clones. Bowersox (1970) found that height growth was correlated with cutting diameter for the first 2 years after planting, but height after 3 years was not related to cutting diameter.

Rooting and field performance of planted cuttings varies with distance from the shoot tip. Bloomberg (1963) observed that rooting capacity of Populus clones increased with distance from stem tip, and reported that basal cuttings of 3 Populus clones had significantly greater root number, total length and weight of roots than cuttings taken from the second 15-cm length from the tip. Hansen and Tolsted (1981) found that cuttings taken from branches, 1-year-old and 2-year-old stemwood of a difficult-to-root clone (P. alba) had comparable survival rates for any given diameter class as cuttings taken from the main stem (Table 4). Cutting survival increased as cutting diameter of both stem and branches increased, and was essentially due to the effects of position. They recommend that branch material be selected on the basis of diameter, but stem material be selected on the basis of both diameter and position, since some of the smaller-diameter basal cuttings still had high survival rates. Height growth increased with cutting diameter for the first 2 months that plants were grown in the greenhouse, but no further effect on height growth was observed. Allen and McComb (1956) found that, with constant cutting diameter, cutting survival and number of roots decreased with age of the parent shoot. They found no survival differences for cuttings of three diameters (0.52, 1.12, and 2.1 cm).

The effect of diameter and stem position on field survival may be attributed to many anatomical and physiological factors. Smith and Wareing (1972a) have shown that preformed root primordia develop acropetally in 1-year-old Populus x robusta coppice shoots throughout the summer and fall, thus root primordia in basal regions develop earlier. Bloomberg (1962) has shown that the anatomy of the basal region of 3 Populus hybrids had wider and fewer vessels than the top region, wider sieve tube zones, and a thicker periderm, thus is more favorable for water storage, retention and translocation. Total carbohydrate reserves are also greater in larger-diameter cuttings. Bud development varies widely along 1-year-old Populus stems with poorly developed buds at the stem base. In addition to developing into the new shoot, these buds also affect root development. Smith and Wareing (1972b) found that removing buds from Populus x robusta cuttings decreased the emergence of root primordia.

Table 4. Relation of cutting numbers and survival to cutting diameter, after 3 months.[1/]

	Stem and Branches		Stem		Branches	
	#Cuttings	% Survival	#Cuttings	% Survival	# Cuttings	% Survival
All cuttings	357	29	144	39	213	22
Greater than 9 mm	102	53	85	53	17	53
Greater than 15 mm	20	65	-	-	-	-

1/ Hansen and Tolsted (1981).

Cuttings are commonly 20 cm (8 inches) in length, although longer cuttings are known to survive better than shorter cuttings under such conditions as moisture stress in the field. On shallow soils, shorter cuttings are generally recommended, and on deeper soils, greater survival will be achieved with 50- to 80-cm cuttings inserted to a depth of 30 to 40 cm (FAO 1979). McKnight (1970) advocated 50-cm cuttings for establishing *Populus deltoides* plantations in the South. Allen and McComb (1956) found that survival, number of roots and shoot growth of 45-cm cuttings was at least double that of 15-cm cuttings.

Parent stems and cuttings should be examined for disease signs, since pathogens causing blackstem, cankers and rusts may be disseminated on planting stock. Blackstem (caused by the fungi *Phomopsis*, *Cytospora* and infrequently *Dothichiza*) can cause deterioration of cuttings, killing them directly in storage or reducing their vigor after planting. Ostry and McNabb (1982) have reported that the presence of each pathogen differed on cuttings collected in Iowa and Wisconsin. The incidence of many *Populus* diseases and insect pests varies widely by region and locality. *Marssonina* and *Septoria* and insect eggs and borers can be present in cuttings, and entire plantations infected if diseased or infested cuttings are planted.

Storage Temperature and Conditions

Most commercial nurseries store cuttings successfully just below or at 0°C for 2 to 4 months before planting (Table 1). Our experience has been that sprouting and root emergence occurs if cuttings are stored just below or above freezing for 5 to 8 months before planting time. For these longer storage periods, cuttings should be held at -10°C or lower to avoid root and shoot development before planting. Cuttings are commonly stored in bundles in one of three microenvironments: (1) moist sand or peat moss around the basal quarter to half of the cutting, covered with moist burlap or held in a humidified environment; (2) in plastic bags in environments where humidity is not controlled; or (3) as entire whips in humidity-controlled rooms.

Generally greater survival and field performance have been achieved by storing cuttings at temperatures several degrees below freezing. For those cuttings stored considerably below 0°C, certain pre-planting treatments may be required for satisfactory growth. Phipps and Netzer (1981) found that cuttings of 4 clones collected in early November rooted and flushed more rapidly if cuttings were stored at 2.8°C than if they were stored at -17.8°C or -3.9°C. This growth retardation was overcome in cuttings stored for one year at -7°C by pre-conditioning the cuttings for 1 or 2 weeks at 2°C then soaking the cuttings until roots began to emerge (Phipps, Hansen and Fege 1983). Phipps and Netzer (1981) found that cuttings of 3 *Populus* clones stored for 4 months at -18°C and -6°C rooted slower than those stored at either 3°C for 4 months, or at 7°C for 2 months followed by 3°C for 2 months. Nearly 100 percent of the cuttings rooted within 22 days of planting, regardless of storage temperature. Cram and Lundquist (1982) found no significant differences between height of cuttings of the Walker clone (*Populus* x *deltoides* Bart. cv. 'Walker') stored at -2°C and 2°C over the winter. However, they reported 82 percent "rooting capacity" of cuttings stored at -2°C from mid-November to mid-May, compared with 73 percent after storage at 2°C and 60 percent after heeling-in outdoors over the winter.

In our studies of 7 *Populus* clones collected in mid-October or later and stored at temperatures from 2°C to -20°C in 1980-81 planted in 1981, and 3 clones stored from 2°C to -10°C in 1981-82, there were no statistically significant survival or height differences by storage temperature, except that some clones collected in October and stored at -20° or -10°C did not survive (Table 3). The pre-planting treatments of "warming" and soaking may have obscured the differences between cuttings stored at various temperatures. For the 1980-81 and 1981-82 studies, cuttings stored at -10°C and -20°C were transferred to 2°C about 3 weeks and soaked in water 1 week prior to planting; cuttings stored at 2°C or -3°C were soaked only 1 day since shoots and roots had begun to grow during storage. Since cuttings stored at the two lower temperatures achieved the same height growth as cuttings stored at near-zero temperatures, the -10°C and -20°C storage temperatures would be advantageous for field operations, since they allow nursery managers greater flexibility in soaking cuttings and scheduling planting.

Minimizing the incidence of disease is an advantage of storing cuttings at freezing temperatures. Development of molds and other organisms on hardwood cuttings and seedlings during storage reduces field survival. Generally, damage is more common when plants are collected early in the fall, storage temperature is above freezing, temperature of storage chamber is allowed to fluctuate, free moisture is present on plant surfaces, and/or storage period is extended several months (Venn 1980). Ostry and McNabb (1982) have shown that incidence of blackstem fungi is lower and survival of cuttings of two hybrid *Populus* clones is higher when cuttings were stored at -3°C rather than at 1°C. *Cytospora* was associated with lower bark moisture in these cuttings.

Cuttings can be bundled and packed in moist sand or peat moss if the storage room has high humidity or if damp burlap covers the cutting bundles. Otherwise, cuttings should be kept in plastic bags during storage. In a study of 5 hybrid *Populus* clones stored at two locations,

cuttings were stored in mulch or plastic bags, or stored as entire whips. For the 3 clones, survival and height growth did not differ significantly between locations or treatments.[4/] For the other 2 clones, there were no differences in either survival or height growth between treatments, with the exception that none of the cuttings stored in the less-controlled environment at Harshaw Farm survived. Cram and Lindquist (1982b) observed that Populus cuttings covered with vermiculite or stored in polyethylene bags at temperatures of -5°C or -1°C showed greater rooting than those stored as bare cuttings, whereas there was no difference between the 3 storage methods at -18°C.

Moisture content in cuttings is influenced by storage conditions. Ostry and McNabb (1982) observed that cuttings stored in plastic bags retained more moisture than those stored unbagged, and resulted in better field survival. In our study of 5 Populus clones stored at 2 locations, moisture content averaged 148 percent for cuttings stored in mulch, 118 percent for those stored in plastic bags, and 84 percent for those stored as entire whips. Cram and Lindquist (1982a) found moisture content to be 136 percent in November-collected cuttings heeled-in outdoors during the winter, with 108 to 123 percent moisture content in cuttings stored at 2°C in plastic bags and 108 percent in cuttings stored at -2°C in plastic bags. It is common practice in France to dip both ends of cuttings in paraffin wax to reduce dessication, with colored wax used to identify the cuttings of different clones (FAO 1979).

Pre-Planting Treatments

The bottom half or three-quarters of cuttings should be soaked in water at about 15°C for 7 to 10 days before planting, until root primordia begin to emerge from the bark and cuttings are fully imbibed. Cuttings may be soaked outdoors in the shade, or in an equipment shed. If cuttings have been stored in plastic bags, the bottom and top of each bag may be punctured to admit water. If roots have begun to emerge and shoots begin to grow during storage, cuttings should be soaked only one day before planting so that moisture content is increased but shoots and roots do not develop further. In order to determine the number of days of soaking needed for root emergence to begin, small tests should be conducted with each clone and storage treatment about a month before planting is scheduled. Nursery managers should soak the cuttings until roots appear as small bumps under the bark surface and begin to break through the bark.

Soaking increases early root growth, essentially extending the growing season. Soaking cuttings for 10 days would be equivalent to a 10 percent increase in the 100-day growing season in northern Wisconsin (Phipps, Hansen and Fege 1983). Petersen and Phipps (1976) found that presoaking stimulated rooting and increased field survival of hardwood cuttings of 3 Populus clones. Root length, root dry weight, percent flush and shoot length increased with duration of soaking (Phipps, Hansen and Fege 1983). In studies of Populus and Salix poles (1.4 to 2.7 m long), Edwards and Kissock (1975) reported that water uptake was most rapid in the first 1-3 days, then followed a logrithmic decline, and that water uptake was maximized by soaking stems vertically rather than horizontally. Shoot and root growth and drought resistance was increased by soaking. Soaking P. deltoides cuttings for 24 hours prior to planting is cited as a method for reducing Dothichiza (FAO 1979), presumably due to the increased moisture content at planting.

Generally, root development proceeds faster at temperatures of about 15°C and under conditions of saturated moisture content. For cuttings which are partly immersed, water should be changed every 2 days or aerated, since oxygen is required for root development. Bloomberg (1963) found that roots produced by cuttings which had moisture content adjusted to 100 percent saturation within polyethylene bags had 5 to 10 times more roots, about twice the total length of roots, and up to 9 times the root dry weight of those produced by cuttings at 50 percent moisture content. When Phipps, Hansen and Fege (1983) made comparisons between soaking 20-cm cuttings to depths of 3 or 15 cm, no significant difference was found for 3 clones, and slightly greater root length and dry weight for only 1 clone, when soaked to 15 cm. Water uptake, bud break, and the emergence of roots proceeded faster in cuttings which were soaked in the dark at 16°, compared with those soaked at 4°C. Bloomberg (1963) held cuttings in polyethylene bags which had moisture content adjusted to fully saturate the cuttings, and found that root number, length and dry weight after 10 days were much lower when cuttings were kept at 5°C, than if they were kept at 15°C or 25°C.

Following observations that soaked cuttings performed far better than unsoaked cuttings when spring weather was exceptionally warm and dry, Phipps and Hansen (1983) evaluated the effects of soil moisture tension on cutting development. Soaking for 4 to 10 days accelerated bud flush over the range of soil moisture tensions (0 to -0.6 bars), with increased shoot length at the high soil moistures. None of the unsoaked cuttings at -0.5 bars flushed by 10 days after

4/Fege, A. S. and H. M. Phipps. 1983. Effect of collection date and storage conditions on field performance of Populus hardwood cuttings. In preparation for Can. J. For. Res.

planting. In field studies of cuttings planted at various dates from snow melt to frost, tree height of soaked cuttings was 13 percent greater than unsoaked cuttings during a wet spring. Allen and McComb (1956) observed 0-20 percent survival in soils at or below field capacity and 61-80 percent survival in soils at moisture contents up to full saturation for 47 days, for unsoaked cuttings. Soaking 50-cm Populus deltoides Bartr. cuttings significantly increased field survival, but the advantage of soaked over unsoaked cuttings were much greater when field conditions were less desirable (Krinard and Randall 1979).

There is some flexibility in the number of days that cuttings can be soaked before planting, depending on the winter storage temperatures and field moisture conditions. When cuttings have reached the proper stage for planting, they may be stored on crushed ice for up to 2 weeks to delay further root extension and shoot development (Phipps, Hansen and Fege 1983). Shoot growth for 4 weeks following planting in soil with adequate moisture was not affected by allowing soaked cuttings to dry for 8 hours at 24°C before planting. After allowing Populus cuttings to dry out for 8 to 14 days (lowering moisture content by 22 to 24 percent), then soaking cuttings in water for 1 day before planting, Bogdanov (1965) reported survival levels of 60 to 75 percent of cuttings which had not been allowed to dry out. In our studies with 7 Populus clones during 2 growing seasons, the cuttings stored at 2°C or -3°C had emergent roots and some flushed buds. Soaking for more than 1 day or delaying planting would have increased mortality of these cuttings. McKnight and Biesterfeld (1968) reported that two companies in the South stored entire whips for a few days in bulldozed trenches filled with water at the planting site, with whips cut into 50-cm lengths just before planting. The basal ends of cuttings were sometimes placed in ditches for a few days before planting, with wet burlap sacks covering them.

When cuttings have been soaked too long and roots have emerged, the process of planting cuttings will break off or damage many of these initial roots. After removing 75 percent and 100 percent of the roots emerging from Populus trichocarpa cuttings which had been incubated in darkness in moistened plastic bags, Bloomberg (1963) reported significantly less shoot growth and fewer roots in the first 9 months, when compared with cuttings planted with all the initial roots intact. Cuttings with 75 percent of their roots removed suffered no greater mortality and had the same root dry weight as cuttings with all their roots intact.

Treatment with fungicides may lessen disease incidence, and indeed, several commercial nurseries included in Table 1 dip their cuttings in fungicides before storage. Hartmann and Kester (1975) recommend that cuttings be dipped in 5 percent benomyl or 24 percent captan after cuttings are made. Two clones known to be susceptible to blackstem injury in early trials were treated with 2 fundicides (1200 ppm) and stored from early March to early June at -20°C, -3°C, and 1°C. Average survival was 58 percent for untreated controls, 70 percent when treated with thiram and 81 percent when treated with benomyl (Ostry and McNabb 1982). Blackstem damage was much lower in cuttings stored at -3°C than those stored at 1°C, and storage of cuttings at -3°C eliminated the need for fungicide use. Ostry and McNabb (1982) also reported that fungicide dips increased survival at 2 sites where adverse growing conditions were found, but that there were no differences at 2 other sites where growing conditions were favorable. Since blackstem develops only on stressed cuttings, they conclude that fungicide dips are not necessary if healthy cuttings and proper handling and storage practices are used, and sufficient water and nutrients are supplied after planting.

There have been various reports of more rapid rooting when auxins are added to the soaking water. Only limited benefit would be achieved in most clones that have performed root primordia since roots emerge after cuttings are soaked in water for a week, but there is evidence that rooting is stimulated in clones which have fewer preformed root primordia (Hartmann and Kester 1975).

Planting Cuttings

Hardwood cuttings should be planted vertically with only 1 or 2 cm of the top of the cutting exposed, and soil well-packed around the cutting. In tests designed to determine the effects of cutting length and planting depth, the least number of main shoots were produced when 20-cm cuttings were planted flush with the ground surface in a silt loam soil. However, first year shoot height was less than that of cuttings planted at shallower depths of either 10 to 15 cm (Hansen et al. 1982). Horizontal planting of cuttings has also been evaluated for various species, but is not generally recommended for Populus. Bloomberg (1963) found that significantly more roots were produced by P. x regenerata and P. x robusta cuttings when placed in upright rather than inverted or horizontal positions, but there was no effect of planting position on P. trichocarpa cuttings.

Cuttings are planted in the spring, after the frost has left the ground and site preparation is completed. This may be as early as March in warmer climates and as late as early June in the northern U.S. Over 3 years, Hansen et al. (1982) found that cuttings planted in mid-May grew consistently more during the growing season than those planted in April, but that differences between planting dates from April to early June were slight. Fall

planting was successful in only 1 of the 3 years due to frost heaving; snowpacks were light in both years that fall planting failed.

Research foresters at the Harshaw Experimental Farm have established up to 8 ha annually with 2 modified planting machine systems. The first consisted of 4 semi-mechanical transplanters model CT-5 mounted on a 15-ft tool bar, pulled by a 85-hp farm tractor. Each of the 4 units can plant about 1200 cuttings per hour at a 1-meter spacing. In a time study of this system, 30,400 cuttings were planted in a 2.9 ha Populus plantation at 1 x 1 m spacing (Mattson and Miyata 1982). The actual planting required 5.6 hours and the estimated planting costs were $98/ha, with lower costs projected for wider spacings. The second planter consisted of 2 Holland transplanter units Model 1525. This was also pulled by a 85-hp tractor. Each unit planted approximately 500 trees per hour. Engineers at the Forestry Sciences Laboratory in Houghton, Michigan, have modified the planter by adding an audible system to control within-row spacing, redesigned the packing system, added larger and stronger planting shoes, and added protective shields for the operators (Hansen et al. 1982). Spacings must be precisely maintained, particularly between rows, in order to facilitate cultivation and minimize damage to stems whenever equipment is maneuvered between the planted rows. For planting 50-cm P. deltoides cuttings, the Southern Forest Experiment Station developed a slit-planting machine that opens a trench with a subsoil chisel, with one worker riding the machine and manually inserting cuttings to the bottom of the trench at the proper within-row intervals. The machine was mounted on a 3-point hitch and drawn by a tractor of at least 85 drawbar horsepower (McKnight and Biesterfeld 1968). During field operations, moisture content of unplanted cuttings should be retained by covering cuttings with moist burlap or by leaving cuttings in plastic bags, and holding cuttings in the shade.

The survival and growth of planted cuttings depends greatly on the availability of soil moisture in the soil or the supplementation of soil moisture by irrigation. In a growth chamber study, Phipps, Hansen and Fege (1983) found that the time required for bud break and early shoot growth increased as soil moisture tentions decreased. Whereas adequate soil moisture is particularly important in the weeks following planting, field performance during the first growing season depends also on adequate moisture, control of competition, soil nutrient levels, and pest management.

Conclusions

Hardwood cuttings are routinely collected, stored and planted by many nurseries in Europe and North America to establish Populus shade trees and plantations. For all the activities required for cutting production, from managing clonal nurseries to planting the cuttings, there are recommended practices based on both practical experiences and knowledge about physiological processes. There is considerable flexibility in some of the practices, particularly in the clonal nursery design, date of cutting collection, sawing and sorting procedures, and duration of soaking cuttings. On the other hand, planting stock vigor and survival can be markedly reduced if storage temperature and duration are not considered together, if there is inadequate soil moisture, and if cuttings are infecte[d] with blackstem diseases. These practices are only recommendations--each nursery must tailor their operations to their region, site, field workers, and Populus clones.

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SURVIVAL AND GROWTH OF TWO INTENSIVELY CULTURED JACK PINE PROVENANCES RAISED IN TUBEPAK AND JIFFY 7 CONTAINERS

J. Zavitkovski and Howard M. Phipps[1]

Abstract.--Container type, provenance, and spacing affect survival, height and d.b.h. growth, and biomass production of intensively cultured jack pine. The Lower Michigan provenance and Tubepak grown plants performed better than the local (Wisconsin) provenance and plants raised in Jiffy 7 pellets. At age 5, biomass of Tubepak plantings was more than 100% higher than that of Jiffy 7 plantings. Plantings of the Michigan provenance had 73% more biomass than those of the local source. The above-ground dry weight yield of the 1.0 x 0.3 m (3.3 x 1 ft) planting at age 5 (60.8 mt/ha (27 tons/acre)), approached yields expected or predicted for hybrid poplar plantations in the Lake States. And jack pine has several advantages over hybrid poplar as a source of biomass for energy: it can be harvested during any season of the year (most hybrid poplars can only be harvested during the dormant season), it can be harvested with stumps and roots (hybrid poplar stumps must be left so new coppice stand can develop), and heat of combustion of jack pine biomass is about 8% higher than that of hybrid poplar biomass.

The present study was designed to show that in suitable containers and under intensive culture, jack pine of a good provenance would grow very rapidly and produce large quantities of biomass. In a previous study (Zavitkovski and Dawson 1978), initial slow growth of jack pine tubelings was traced to the small size and rigid walls of the plastic container that restricted root development and seedling growth. At age 2, the average height of the tubelings was at least 1 year behind that of freely developing seedlings raised under less intensive cultural conditions (Jeffers and Nienstaedt 1973).

In this study we compared survival, and height and d.b.h. growth of two jack pine provenances, a local and a recommended Lower Michigan provenance (Jeffers and Jensen 1980) grown in two containers -- Jiffy 7 pellets and Tubepaks -- at three spacings.

The study was established in 1978 on the Harshaw Forestry Research Farm located about 10 miles west of Rhinelander, WI. The land of the farm is level and was used for about 50 years to grow potatoes. The Farm is operated by researchers at the Forestry Sciences Laboratory, Rhinelander, WI.

MATERIALS AND METHODS

Seed from the Lower Michigan provenance was collected in 1974 from Grand Traverse County, latitude 44.5°N and assigned number NC-7738. Seed from the Wisconsin provenance, number NC-8806, was collected in the winter of 1975/76 from Oneida County, latitude 45.75°N. All seed was kept in cold storage until the beginning of this study.

After a brief stratification, the germinating seed was planted in Jiffy 7 pellets and Tubepak containers[2/3/] filled with a 3:1:1

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[2] The Jiffy 7, manufactured by Jiffy Products of America, is a compressed pellet of peat moss (with fertilizer) that expands upon soaking to form a container about 4 cm (1 3/4 inches) in diameter and 5 cm (2 inches) high (ca. 78 cm^3 or 5 cu in). A plastic net holds the container together. The Tubepak is a semitransparent plastic container that has several cavities each measuring 4 x 5 x 18 cm (1½ x 2 x 7 in) (ca. 266 cm^3 or 17 cu in). It is made up of two parts that can be separated to permit removal of the seedlings for transplanting.

mix of peat, vermiculite, and perlite. They were grown for 5 months (December 1, 1977 to April 30, 1978) in a greenhouse using standard treatment including frequent watering, application of balanced nutrient solution, and daylength extended to 16 hours with incandescent light.

In May 1978, we moved the seedlings into a shadehouse to harden them off and bring them into a dormant stage to ensure thay they would resume growth in the field. The treatment was only partly successful. Many of the seedlings did not set bud, remained succulent and had to be planted carefully to keep them in a vertical position.

At age 6 months, before outplanting, heights of the seedlings averaged:

Container	Grand Traverse, MI	Oneida, WI
	Mean (SD), cm	
Jiffy 7	18.4 (4.2)	17.5 (3.7)
Tubepak	19.4 (3.8)	19.6 (3.2)

Only heights of the Oneida County seedlings (17.5 vs 19.6) were significantly different (at the 5% level).

The seedlings were hand-planted in rows 1 m (3.3 ft) apart. Three spacings were achieved by planting seedlings 0.3 (73 seedlings/row), 0.6 (41 seedlings/row), and 1.0 m (25 seedlings/row) (1, 2, and 3.3 ft) within rows. Seven rows were planted for each of the 6 spacing-container combinations, for a total of 42 rows per provenance. Seedlings from the two sources were planted in blocks separated by a 4 m (13 ft) lane, and one border row was provided around the entire 0.3 ha (0.75 acre) study area. Soil is in the Padus series grading from a silt loam to a sandy loam with sand to gravelly sand subsoil.

The plantings were irrigated when the soil moisture tension reached - 0.5 bar as measured at the 15-30 cm (6-12 in) depth with tensiometers. They were fertilized annually with 112 kg/ha (100 lbs/acre) N applied in several applications through the irrigation system.

All live trees were counted at the end of each growing season. In the middle 3 rows of each spacing-container combination, height was measured every year from age 2. At ages 4 and 5, d.b.h. was measured on 10 systematically selected live trees/row.

[3] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such does not constitute an official endorsement by the U.S. Department of Agriculture of any product or service to the exclusion of others thay may be suitable.

RESULTS AND DISCUSSION

All three main variables -- provenance, container type, and spacing -- strongly affected survival and height and d.b.h. growth. In most instances, differences between average values were consistent from 1 to 5 years.

Survival

Plants raised in Tubepak containers and the Michigan seed source had a higher survival than plants raised in Jiffy 7 pellets and the Wisconsin (local) seed source (Table 1). Most of the mortality occurred during the first year in the field and, generally, was low during the subsequent 4 years. Density effects on survival were not consistent -- overall survival at age 5 averaged 76, 71, and 77% in plantings spaced at 1.0 x 0.3, 1.0 x 0.6, and 1.0 x 1.0 m, respectively.

At age 5, the Michigan provenance raised in Tubepak containers had the highest survival -- 89% -- and the local provenance raised in the Jiffy 7 pellets had the lowest survival -- 61% (Table 1). In the previous study (Zavitkovski and Dawson 1978), the survival of the jack pine tubelings at age 4 ranged from 84 to 100%. In Minnesota, jack pine tubelings under field conditions had a 77% survival at age 2 and 65% at age 5 (Alm and Schantz-Hansen 1970, 1972). These tubelings were much shorter than our intensively cultured jack pine.

Height and d.b.h. growth

At the end of the greenhouse phase (6 months), seedlings raised in the Tubepak containers were taller than those in the Jiffy 7 pellets, but it was not yet clear which of the two sources might be better. The superiority of the Michigan source became evident at age 2 and significant at age 5 (Table 1).

At age 2, plants of the Michigan provenance were about 23% taller than those of the local provenance, and at age 5 they were about 4% taller. However, the height difference remained about the same -- 10 cm (4 in) -- as at age 2. The mean difference in height between plants raised in Tubepak containers and Jiffy 7 pellets was 29% at age 2 and 16% at age 5. However, the absolute height difference was 12½ cm (5 in) at age 2 and 35 cm (11 in) at age 5 in favor of the Tubepak plants. This shows that the effect of container type on height was greater than the effect of provenance through age 5.

Spacing effect on height growth, like that on survival, was inconsistent. The average maximum height of 280 cm (9.2 ft) was reached at age 5 in the Michigan planting spaced 1.0 x 0.3m (Table 1). The most uniform average heights -- from 232 to 253 cm (7.6 to 8.3 ft) -- were reached in the 1.0 x 1.0 m plantings of both provenances.

Table 1.--Survival, height, and dbh of 1- to 5-year-old intensively cultured jack pine

	SURVIVAL (%)				HEIGHT (cm)[1/]				DBH (mm)[1/]			
	MICHIGAN		WISCONSIN		MICHIGAN		WISCONSIN		MICHIGAN		WISCONSIN	
AGE	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK
SPACING: 1.0 x 0.3 m (Initially 73 seedlings per row.)												
1	79	95	74	85								
2	77	94	67	83	48	65	40	49				
3	76	93	63	82	113	140	89	108				
4	74	93	63	78	182	212	149	172	12	17	7	10
5	71	92	63	76	236^{c} [3/]	280^{a}	210^{d}	256^{b}	22^{b}	26^{a}	17^{c}	20^{bc}
SD[2/]					37	29	36	38	8	8	6	6
SPACING: 1.0 x 0.6 m (Initially 41 seedlings per row.)												
1	70	96	82	91								
2	64	94	68	90	45	66	40	50				
3	64	93	63	89	92	126	87	123				
4	57	91	63	88	141	203	149	190	7	16	7	14
5	54	86	59	86	216^{b}	261^{a}	215^{b}	263^{a}	19^{c}	29^{a}	19^{c}	25^{b}
SD[2/]					46	35	33	28	9	9	7	5
SPACING: 1.0 x 1.0 m (Initially 25 seedlings per row.)												
1	82	95	69	90								
2	81	95	68	87	50	58	40	52				
3	78	95	66	87	108	125	95	120				
4	76	89	60	83	174	191	149	184	12	14	8	14
5	75	89	60	83	242^{ab}	253^{a}	232^{b}	249^{a}	26^{ab}	28^{a}	22^{b}	26^{ab}
SD[2/]					40	45	30	33	10	10	7	8
ALL 3 SPACINGS POOLED												
1	77	95	75	89								
2	74	94	68	87	48	63	40	50				
3	73	94	64	86	104	130	90	117				
4	69	92	62	83	166	202	149	182	10	16	7	13
5	67	89	61	82	231	265	219	256	22	28	19	24

1/ To convert centimeters and milimeters into inches multiply by 0.394 and 0.0394, respectively.
2/ Standard deviation for age 5 of height and d.b.h. is based on 30 measurements, i.e., 10 per row in the middle 3 rows.
3/ At age 5, average heights and d.b.h.'s are not significantly different (at the 5% level) if followed by the same letter.

The effect of spacing on d.b.h. growth was essentially positive. This trend was clearly demonstrated in trees from the Wisconsin source but although it was present, it was not so obvious in trees from the Michigan source.

At age 5, the average height of the trees -- 210 to 280 cm (almost 7 to more than 9 ft) -- was substantially greater than that of the Tubeling jack pine -- 170 to 194 cm (5½ to 6½ ft) -- used in the previous study (Zavitkovski and Dawson 1978). Actually, the heights were within the range of the 6-year-old tubeling trees (247 to 277 cm or 8 to 9 ft).

Our plants grew equally well or better than intensively cultured jack pine in other studies. Three-year-old seedlings of the best Lower Michigan Peninsula provenance averaged 130 cm under nursery culture which included fertilization and irrigation (Canavera and Wright 1973). In our study, 3-year-old seedlings from the Michigan source raised in Tubepaks averaged 130 cm and in the 1.0 x 0.3 m planting averaged 140 cm (Table 1). In a provenance test at Rhinelander, 2-year-old plants of the best Lake States provenances, raised in Jiffy 7 pellets, averaged 50 cm in height (Jeffers and Nienstaedt 1973). Heights of our 2-year-old plants ranged from 40 to 63 cm.

In traditionally cultured plantations, jack pine grows more slowly and height at age 4 averages only about 112 cm in northern Wisconsin (Rudolph 1981); 83 cm in Vermont (Adams 1928); and from 54 to 60 cm in Michigan (Rudolf 1951). At age 5, height of field-planted jack pine tubelings averaged 76 cm in Minnesota (Alm and Schantz-Hansen 1972), bare root planted stock averaged 116 cm in Vermont (Adams 1928) and from 98 to 129 cm in Ontario (Logan 1966, Yeatman 1974).

The d.b.h. of our 5-year-old plants ranged from 18 to 30 mm (0.7 to 1.2 in) (Table 1), and was similar to the d.b.h. reached by 7-year-old trees -- 17 to 30 mm -- in the previous study (Zavitkovski and Dawson 1978). D.b.h. of field-planted jack pine ranged from 19 to 33 mm (0.7 to 1.3 in) in a 10-year-old plantation established with 1-0 stock in Lower Michigan (Rudolf 1951). Not only the d.b.h., but also the average height of these plants was similar to our 5-year-old, intensively cultured jack pine.

Aboveground tree biomass

We estimated total aboveground biomass (including needles) of our 4- and 5-year-old plantings by means of an equation developed for 6- and 7-year-old intensively cultured jack pine spaced at 0.6 x 0.6 m (2 x 2 ft) (Zavitkovski and Dawson 1978):

$$\ln \text{Aboveground biomass} = -6.5642 + 2.1891 \ln \text{d.b.h.}$$

In this equation, biomass is in kg, d.b.h. is in mm, $R^2 = 0.9411$, $s_{y.x} = 0.2124$, and the correction factor is 1.0228. Stems, branches, and needles accounted for about 45, 29, and 26% of the total biomass, respectively.

Container and provenance effect on dry weight was greater and more variable than their effect on height and d.b.h. In general, biomass decreased as spacing increased (Table 2). Biomass of plantings established from seedlings grown in Tubepaks was from two to several times greater than that of plantings established from seedlings grown in Jiffy 7 containers. The most biomass was in the 1.0 x 0.3 m planting of the Michigan source raised in Tubepaks -- about 60.8 mt/ha at age 5 -- and the least was in the 1.0 x 1.0 m planting of the local source raised in the Jiffy 7 pellets -- about 8.2 mt/ha. Previous studies have demonstrated that total biomass differences between dense and open plantations gradually diminishe (Zavitkovski and Dawson 1978).

The highest total tree aboveground biomass achieved in this study - 60.8 mt/ha -- was about 10% higher than the maximum -- 56.8 mt/ha -- reached in the previous study (Zavitkovski and Dawson 1978) at age 7. This yield approaches mean annual biomass increments expected or predicted for various hybrid poplars. However, jack pine has three advantages over poplar: (1) it can be harvested with roots that may amount to about 20% of the aboveground biomass, i.e. about 12½ mt/ha at age 5; (2) it can be harvested at any time of the year whereas hybrid poplars must be harvested during the dormant season (Strong and Zavitkoski 1982) to ensure the best coppice regeneration; and (3) its heat of combustion is about 8% higher than that of hybrid poplar. Its main disadvantage is that it has to be replanted after each harvest, whereas poplars regenerate by coppicing. These points should be considered when deciding which species to use in energy plantations.

Container effect

The difference in growth between seedlings raised in the Tubepak and Jiffy 7 containers may be partly explained by the difference in container volume. The larger volume of the Tubepak would permit the development of a larger root system. However, some evidence suggests that the plastic net surrounding the Jiffy 7 container may deform or restrict the normal development of the root system of some tree species as they grow older. In the present study, the difference in height, d.b.h. and particularly total dry weight of Tubepak and Jiffy 7 plants appeared to be increasing through age 5 (Tables 1 and 2).

Table 2.--Preliminary estimates of above-ground tree biomass of 4- and 5-year old intensively cultured jack pine[1/] (In metric tons per hectare)[2/]

SPACING	AGE	MICHIGAN		WISCONSIN	
m	yrs.	JIFFY 7	TUBEPAK	JIFFY 7	TUBEPAK
1.0 x 0.3	4	11.9	25.3	3.6	7.4
	5	33.3	60.8	16.0	28.1
1.0 x 0.6	4	2.2	10.7	1.8	7.5
	5	10.0	36.2	10.3	25.5
1.0 x 1.0	4	3.3	4.9	1.4	4.3
	5	16.1	23.1	8.2	15.8

1/ Stems, branches, and needles accounted for about 45, 29, and 26%, respectively.
2/ To convert metric tons per hectare into tons per acre multiply by 0.445.

After 2 years in the field, we found that poplar hybrid cuttings rooted in Jiffy 7 pellets were consistently shorter than those rooted in a similar container but without the plastic net coverings.[4/] An examination of the root systems of several poplar hybrid trees propagated in Jiffy 7 containers and grown for 6 months in pots in a greenhouse showed fewer long roots than those grown in pots without the container. Also, roots of the former plants tended to grow horizontally and to have a spiral configuration.

CONCLUSIONS

1. Results of the study indicate that selection of container type, provenance, and spacing is extremely important and may affect survival, height, d.b.h., and biomass of jack pine plantations for at least 5 years.
2. In the field, plants from the Michigan source and Tubepaks had a higher survival -- by 6½% for the source and 21% for the container at age 5 than those from the Wisconsin source and Jiffy 7 pellets.
3. The effect of container type on height showed up at age 6 months in the greenhouse, became significant at age 2 years in the field, and then remained about the same through age 5 -- about 22% in favor of the Tubepaks.
4. Provenance had no effect on height in the greenhouse. In the field, the difference reached about 20% in favor of the Michigan source at age 2 and then gradually decreased to 4% at age 5.
5. Container type and provenance had a greater effect on diameter than on height. At age 5, Tubepak plants had a 24% greater d.b.h. than Jiffy 7 plants, and the Michigan source had a 14% greater d.b.h. than the one from Wisconsin.
6. The greatest effect of the container type and provenance showed up in total biomass, which incorporates both height and d.b.h. differences. At age 5, biomass of the Tubepak plantings was 102% greater than that of Jiffy 7 plantings. Plantings of the Michigan source had 73% more biomass than those of the Wisconsin source.
7. From age 1 to 5, the densest plantings had the greatest biomass. At age 5, the overall averages were 35, 20, and 16 mt/ha in plantings spaced at 1.0 x 0.3, 1.0 x 0.6, and 1.0 x 1.0 m, respectively.
8. The highest aboveground yield of 60.8 mt/ha at age 5 approaches yields reached in hybrid poplar plantations. The advantages of jack pine over hybrid poplars are (1) it can be harvested at any time of the year; (2) it can be harvested with roots; and (3) its heat of combustion is about 8% higher.

[4/] H. M. Phipps, unpublished data.

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MYCORRHIZAE OF POPLARS[1]

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Abstract. Poplar hybrids, being screened for short-rotation intensive culture, can form ecto-, endo-, or ectendo-mycorrhizae or may be autotrophic. Different sections of the genus Populus tend to be selective in the type of mycorrhizae formed. Knowledge of which types are formed influences the kinds of propagule production, site preparation, and herbicide techniques that should be used in establishing poplar plantations.

INTRODUCTION

Since 1970, the North Central Forest Experiment Station at Rhinelander, Wisconsin, has been screening Populus clones on the basis of their growth potential for short-rotation intensive culture (SRIC). Specific studies have been conducted on the relationship between morphological and physiological variables and the quantity and quality of yield for selected clones. However, a better understanding of the physiological interactions in the root zone of SRIC poplars is needed to improve cultural practices and yields. One of the most important interactions in the root zone is the symbiosis between roots and fungi called mycorrhizae. This research was conducted to describe the importance of mycorrhizae to the establishment and growth of Populus trees.

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With few exceptions, all plants in nature develop mycorrhizae to various degrees. Wilhelm (1966) states that, under field conditions, plants do not, strictly speaking, have roots, but rather, mycorrhizae. Mycorrhizae have been shown to improve the growth of trees through their influence on nutrient and water uptake, disease resistance, high temperature tolerance, and hormone interactions. However, most of the major research efforts reported in the literature to date have been on nutrient-uptake interactions. The two major types of mycorrhizae most frequently encountered are "ectomycorrhizae" and "endomycorrhizae." A third type, "ectendomycorrhizae," is less frequently encountered and poorly understood.

Ectomycorrhizae

Ectomycorrhizal infection is initiated from spores or hyphae (collectively referred to as "propagules") of certain fungal symbionts in the rhizosphere of feeder roots. These propagules are stimulated by root exudates and grow vegetatively over the feeder-root surface, forming the external fungal mantle. After mantle development, hyphae develop intercellularly in the root cortex, forming the "Hartig-net," which may completely replace the middle lamellae between cortical cells. This Hartig-net is the major diagnostic feature of ectomycorrhizae. Ectomycorrhizae may appear either as simple unforked roots, bifurcate roots, multiforked

roots, or even nodular-like roots that are readily visible to the naked eye. The visible structures are commonly referred to as "short roots." Each individual short root, regardless of branching pattern, is an ectomycorrhiza. Individual hypha, multiple hyphae, or rhizomorphs may radiate into the soil from the fungus mantles on short roots and eventually unite with the base of fruiting bodies of the fungus (Marx, 1975; Smith, 1980).

It is estimated that more than 2100 species of ectomycorrhizal fungi exist on trees in North America. Most fungi that form ectomycorrhizae with forest trees are Basidiomycetes that produce mushrooms or puffballs as reproductive structures. However, certain of the Ascomycetes, such as truffles, also are symbiotic. The fruiting bodies of these fungi produce millions of spores that are widely disseminated by wind and water. Moreover, most ectomycorrhizal fungi are dependent on their tree hosts for essential carbohydrates, amino acids, vitamins, etc., needed to complete their life cycle. Thus, ectomycorrhizal development with a host is usually a prerequisite for fruiting-body production by these fungi.

Under normal forest conditions, many species of fungi may be involved in the ectomycorrhizal associations of a forest, a single tree species, an individual tree, or even a small segment of lateral root. Indeed, as many as three species of fungi have been isolated from an individual ectomycorrhiza (Marx, 1975). A single species of fungus may also enter into ectomycorrhizal association with numerous tree species. Some of the fungi may be rather host specific, but little work has been done on this phenomenon.

Ectomycorrhizae occur naturally on many of the important forest tree species of the world. All members of the gymnosperm family Pinaceae are ectomycorrhizal; i.e., Pinus (pine), Picea (spruce), Abies (fir), Larix (larch), Tsuga (hemlock), and Pseudotsuga (Douglas-fir), as well as certain angiosperms such as Salix (willow), Populus (aspen), Carva (hickory and pecan), Quercus (oak), and Fagus (beech).

Endomycorrhizae

Endomycorrhizal fungi, commonly referred to as the "vesicular-arbuscular" fungi, are the most widespread and important root symbionts. They are not restricted to specific groups of plants, but occur in practically all families of angiosperms, gymnosperms, and many pteridophytes and byrophytes. Most of the economically important grain and forage crops, as well as the major berry crops and fruit and nut trees, normally form endomycorrhizae. Many of our most important forest trees, such as Liquidambar (sweetgum), Platanus (sycamore), Ulmus (elm), Juglans (walnut), Fraxinus (ash), Liriodendron (yellow poplar), and Populus (cottonwood), form endomycorrhizae. Although endomycorrhizal fungi can form a loose network of hyphae on feeder-root surfaces, they do not develop the dense fungal mantle found on the ectomycorrhizae. Instead, endomycorrhizal fungi form large, conspicuous, thick-walled spores on the root surfaces, in the rhizosphere, and sometimes in feeder-root tissues. Endomycorrhizal fungal hyphae penetrate the cell walls of the epidermis and subsequently grow into the cortical cells of the root. Once in the cortical cells, these infective hyphae may develop specialized absorbing or nutrient-exchanging structures called "arbuscules." Arbuscules consist of dense clusters of very fine dichotomously branched filaments that may occupy the entire lumen of the cell. Vesicles develop later, generally in the middle and outer cortex, and appear as terminal swellings either within or between cells. No external morphological changes occur in roots infected with endomycorrhizal fungi, although with some hosts, a yellow or brown color in the roots has been reported. Endomycorrhizal fungi rarely invade meristematic tissue. Many conflicting opinions have been expressed about the functions of the arbuscules. Generally, vesicles are regarded as temporary storage organs for the fungus, and arbuscules as the exchange sites between the fungus and the host cell.

The fungi that form endomycorrhizae are mainly Phycomycetes. They do not produce large, above-ground fruiting bodies or wind-disseminated spores as most ectomycorrhizal fungi do. Some of them produce large azygospores and chlamydospores on or in the roots, whereas others produce large sporocarps (5 to 10 mm diam.) containing many spores. Spread of of these fungi in soils is by root contact, moving water, insects, or animals. In the absence of a host, the spores of these fungi are still able to survive in the soil for many years. As with ectomycorrhizal fungus spores, endomycorrhizal spores apparently are stimulated to germinate by root exudates in the rhizosphere.

Ectendomycorrhizae

Ectendomycorrhizae have some of the features of both ecto- and endo-mycorrhizae. They have a limited occurrence and, with regard to forest trees, are found primarily on roots of ectomycorrhizal trees. However,

very little is known about the species of fungi involved or their importance to the growth of trees because little research has been done on them.

Poplar Mycorrhizae

Relatively little is known about poplar mycorrhizae. Walker (1980) made a detailed survey of the literature concerning the mycorrhizae of *Populus*. He listed all assumed or proven mycorrhizal fungal associates with *Populus* species (Table 1). Twenty poplar species were shown to be mycorrhizal and all or any of the three major types of mycorrhizae; ecto-, endo-, and/or ectendo-mycorrhizae may be present. Eight poplar species are also shown to be capable of autotrophic growth without mycorrhizae. Poplars can be mycotrophic or autotrophic, depending on age and environmental conditions (Dominik, 1956, 1958). This ability is seen as an advantage for pioneer species that usually become established on drastically altered sites where mycorrhizal fungal inoculum may not be readily available.

Very little work has been done on the ecology and physiology of mycorrhizal poplars. However, Walker and McNabb (1983) recently assessed growth differences and mycorrhizal conditions of seven clones of poplar that were grown from rooted cuttings in five different unsterilized Iowa soils for 1 year in a greenhouse. Four of the soils were from central Iowa, and the fifth was from northeastern Iowa. Two of the soils were from woodland sites where *Populus grandidentata* Michx. was the major tree species, and one soil from an oak-hickory-elm woodland where *Populus* spp. were absent. The other two soils were from agricultural sites (corn-soybean fields). One of these soils had received frequent fertilizer and herbicide applications while the other had never been treated with agricultural chemicals. The seven clones used are given in Table 2. All three major types of mycorrhiza were found in the genus *Populus*. Their results also suggest that there may be differences in mycorrhizal development between the different sections of *Populus*. NC-5260 (North Central Forest Experiment Station (NC) number 5260), of the Tacamahaca group, seemed able to form any of the three types of mycorrhizae. NC-5339, of the Leuce group formed ecto- and ectendomycorrhizae, but formed only a few endomycorrhizae. The *P. euramericana* clones, of the Aigeiros group, formed many endomycorrhizae but did not form either of the other two mycorrhizae.

In another study, Walker et al., (1982) planted four clones of hybrid poplars at two locations in central Iowa to investigate the development of mycorrhizae over time and the changes in their populations in the soil. The four clones used were four of the same ones used in the previous study; namely, NC-5260, NC-5323, NC-5326, NC-5339. One of the sites was a sandy terrace near the Des Moines River, well above flood level. This site was occupied by poorly growing white ash (*Fraxinus americana* L.). The second site was meadow land on a silt-loam soil in the floodplain of a small stream that occasionally flooded. Vegetation on this site consisted of a mixture of grasses, smooth brome (*Bromus inermis* Leyss.), and foxtail (Setaria spp.). Both sites were tilled, and then rooted cuttings were planted. During the growing season, cuttings were periodically excavated, and plant root and rhizosphere soil samples collected.

A total of 15 species of endomycorrhizae were found on the two sites (Table 3). Ten of those were found at the first site, and 12 at the second site. This diversity was greater than the 3 to 5 species per site that have been commonly reported in the literature. Walker et al. (1982) suggest that these numbers were not unrealistic, but, rather, the result of more intensive and careful sampling. The spatial distribution of species spores were usually unevenly grouped over the site. This grouping was thought to be related to association of fungi to previous vegetation distribution. No differences were found in spore numbers related to clones, suggesting that clones either had no effect or had similar effects on spore production. There was little mycorrhizal development on the poplar roots despite large numbers of spores in the soil. This supports the idea that the trees had little influence on the spore populations. Spore numbers in the soil tended to be least in spring and greatest in late summer and early autumn. These differences might be directly or indirectly related to soil moisture conditions. Plowing and herbicide application could depress spore production. Walker et al. (1982) concluded that, although there are large numbers of spores available on many sites, a knowledge of the fungal species and their diversity, distribution, and population levels would be useful in determining site preparation and planting strategies for poplar plantations.

Table 1. Mycorrhizal status of poplars surveyed for mycorrhizae by Walker (1980). (+ = present; - = absent; blank = no data.)

Genus section and poplar species[a]	ect[b]	ecten[b]	end[b]	aut[b]
Leuce				
P. alba	+		+	+
P. canescens	+			
Aigeiros x Leuce				
P. nigra x *alba*	-		+	-
Aigeros				
P. deltoides	+		+	+
P. x *euramericana*	+	+	+	+
P. fremontii S. Wats.	+		-	
P. x *marilandica*	+		+	-
P. nigra	+		+	-
P. regenerata Henry	+		-	-
Tacamahaca x Aigeiros				
P. x *berolinensis*	+		+	-
(Tacamahaca x Aigeiros) x Aigeiros				
P. x *generosa* Henry x *nigra*	+		+	
Tacamahaca				
P. angustifolia	+			
P. balsamifera	+			
P. candicans Aiton	+		-	-
P. trichocarpa	+			
Leucoides				
P. heterophylla L.	-		-	+
Tremulae				
P. grandidentata Michx	+		-	
P. tremula	+	+	+	-
P. tremuloides	+		+	
Tremula x Aigeiros				
P. tremula x *P.* x *euramericana*	+		-	-

[a] Includes varieties and subspecies.

[b] ect = ectomycorrhizal; ecten = ectendomycorrhizal; end = endomycorrhizal; aut = autotrophic.

Table 2. Overall mean mycorrhizal colonization levels for seven poplar clones grown for a year in a greenhouse in five Iowan soils. Minimum = 0, maximum = 3. Endo = endomycorrhiza, Ecto = ectomycorrhiza, Ecten = ectendomycorrhiza (Walker and McNabb, 1983).

Clone	Parentage of clone	Genus section	Endo	Thin-mantled Ecto	Ecten
NC-5260	P. tristis x P. balsamifera	Tacamahaca	2.12	0.08	0.36
NC-5323	P. x euramericana	Aigeiros	2.04	0	0
NC-5326	P. x euramericana	Aigeiros	1.80	0	0
NC-5328	P. x euramericana	Aigeiros	1.96	0	0
NC-5377	P. x euramericana	Aigeiros	1.80	0	0
NC-5339	P. alba x P. grandidentata	Leuce x Tremulae	0.24**[a]	0.48	0.44

[a]**Significantly lower than others in the same column (p = 0.01).

In this paper, we also report the results of a study on the mycorrhizal condition and growth of two SRIC poplar clones in the establishment year. The objective of this study was to determine whether two diverse Populus hybrids become ecto- or endo-mycorrhizal, or remain autotrophic when grown in soils inoculated with an ectomycorrhizal or endomycorrhizal fungus or with natural inoculum.

METHODS

The study was conducted at the North Central Forest Experiment Station's Harshaw Experimental Farm near Rhinelander, Wisconsin, during the summer of 1980. The two Populus clones used in the study were Populus Tristis Fisch. x P. balsamifera L. cv. 'Tristis #1' (NC-5260) and Populus euramericana (Dode) Guinier cv. Eugenii (NC-5326). The hardwood cuttings used for the study were collected from a cutting orchard at the farm and were approximately 25 cm long.

The mycorrhizal fungi used were produced at the IMRD. The ectomycorrhizal fungus was Pisolithus tinctorius (PT) grown in pure culture by the techniques of Marx and Bryan (1975). The endomycorrhizal fungus was Glomus fasiculatus (GF) produced by growing the fungus in sorghum (Sorghum vulgare (Stapf.) Haines var. roxburghii) pot cultures. The soil and roots of these pot cultures were

Table 3. Species of endomycorrhizae found in surveys of soil collections made at two field sites in central Iowa. (Walker and McNabb, 1983b.)

Fungal species on the sandy terrace	Fungal species on the silt-loam flood plain soil.
ACAULOSPORA spp.	
A. scrobiculata Trappe	*A. scrobilculata*
A. spinosa Walker & Trappe sp. ined.	*A. spinosa*
	A. trappei Ames & Linderman
GIGASPORA spp.	
Gi. calospora (Nicol. & Gerd.) Gerd. & Trappe	*Gi. calospora*
Gi. gilmorei Trappe & Gerdmann	*Gi. gilmorei*
Gi. rosea Nicolson & Schenk	
Gi. heterogama (Nicol. & Gerd.) Gerd. & Trappe	
GLOMUS spp.	
	Gl. albidus Walker & Rhodes sp. ined.
Gl. constrictus Trappe	
	Gl. epigaeus Daniels & Trappe
Gl. fasciculatus (Thaxter sensu Gerd.) Gerd. & Trappe	*Gl. fasciculatus*
Gl. geosporus (Nicol. & Gerd) Walker stat. ined.	*Gl. geosporus*[a]
	Gl. microcarpus Tul. & Tul.
Gl. mosseae (Nicol. & Gerd.) Gerd. & Trappe	*Gl. mosseae*
	Gl. occultus sp. ined.

[a]= *Glomus macrocarpus* var. *geosporus* (Nicolson & Gerdemann) Gerdemann & Trappe.

used as inoculum. The natural inoculum consisted of unidentified fungal symbionts contained in the unfumigated soil from the farm. The soil was a sandy loam with the following chemical analysis: 35mg/l Bray 1 extractable P, 237mg/l total P, 323mg/l total Kjeldahl nitrogen, 14mg/l extractable NO_3-N, 68mg/l K, 160mg/l Ca, 619mg/l, Al, 71mg/l Fe, a pH of 5.3, and 1.04% organic matter. The soil was fumigated with methyl bromide (Dowfume MC-2, Dow Chemical Co., Midland, MI 48604)[3] at a rate of 450g per 12m2 of soil surface (15cm deep).

The study was conducted in 1m x 1m x 1m wooden boxes similar to those used in numerous previous studies (Kormanik et al., 1981, 1982; Schultz et al., 1981, 1982). The bottoms of the boxes were filled with approximately 15cm of coarse gravel to facilitate drainage.

The study as a 2x4 factorial with 3 replications set up as a split plot in a randomized complete-block design. Whole-plot treatments consisted of either fumigated or unfumigated soils. Within the fumigated soils, there were three treatments. One was inoculated with PT at the rate of 1 liter per box (FPT), one was inoculated with GF at the rate of 1 liter per box (FGF), and one was left uninoculated (FC) as a control. The unfumigated soil (UF), with its natural inoculum, was the fourth treatment. Inoculum was mixed into the top 20cm of soil to allow contact with the full length of the cutting.

Soil pH was adjusted to 6.0 by adding hydrated lime ($Ca(OH)_2$) at the rate of 183g per box. No phosphorus or potassium fertilizer was added because low phospohrus was desired and potassium levels were sufficient for tree growth. A total of 1680kg/ha of NH_4NO_3 was added at eight equally spaced intervals throughout the study (21g/box, per addition).

Ten cuttings of each clone were planted in two adjacent rows in each box. Clones (subplots) were randomly assigned to the two sets of rows in each box. In the FPT treatment, five Jack pine (Pinus banksiana L.) were also planted to test the viability of the PT inoculum. PT is known to readily infect pine.

Growth responses to the treatments were measured twice during the study. The first measurement was done August 15, 1980. At that time, height, diameter, number of leaves, and leaf area were measured. The study was harvested October 15, 1980. In addition to these measurements, dry weights of the leaves, stems, cuttings, and roots were collected at this time. Ten percent of the fine feeder roots of each cutting were collected for mycorrhizal analysis. The endomycorrhizal roots were stained and analyzed according to a method of Kormanik et al. (1980). Ectomycorrhizal assays were made according to a method of Dr. Donald Marx of the IMRD (pers. commun.)

The data were analyzed by analysis of variance. Significant treatment differences were identified by use of the following orthogonal contrasts: 1) unfumigated vs. all the fumigated, 2) the fumigated control vs. fumigated inoculated, and 3) ectomycorrhizal vs. the endomycorrhizal treatment.

RESULTS AND DISCUSSION

Treatment Responses

There were no height growth differences among treatments at either of the two measurement dates (Table 4). It is possible that the large carbohydrate reserve in the cuttings may have been responsible for the lack of response. A two or more year study probably would be necessary to describe these treatment differences. On the other hand, it is possible that competition resulting from the close spacing of the cuttings in the boxes resulted in the similar height-growth responses among all treatments. Preferential allocation of photosynthates to stem elongation reduced the carbohydrates available for biomass production and diameter growth in some treatments.

There were no differences among treatments in the August measurement of cutting diameters (Table 4). By the middle of October, however, the cuttings growing in the UF soil had a significantly smaller diameter than those growing in any of the fumigated treatments (Table 5). These differences may be the result of a greater and more diverse

[3]Use of trade names is for convenience of the reader and does not constitute an endorsement by the USDA Forest Service.

Table 4. First season growth data for Tristis (NC-5260) and Eugenei (NC-5326) cuttings rooted under the following soil treatments: 1) fumigated soils that were a] inoculated with an endomycorrhizal fungus (FEN), or b] inoculated with an ectomycorrhizal fungus (FEC), or c] uninoculated (FC); or, 2) unfumigated soils with natural inoculum.

	Height (m)	Diameter (cm)	Number of leaves	Leaf area (cm^2)	Height (m)	Diameter (cm)
Clone						
NC-5260	0.88	0.86	45	5867	0.88	0.90
NC-5326	0.74	0.73	39	5674	0.92	0.95
Treatment						
UF	0.80	0.78	33	5474	0.86	0.88
FC	0.83	0.82	46	5918	0.94	0.96
FGF	0.81	0.81	41	5734	0.90	0.95
FPT	0.79	0.79	47	5958	0.89	0.92
Significance[a]						
Clone	**	**	**	--	--	*
Treatment	--	--	**	--	--	*
Contrasts[b]						
UF vs. all	--	--	*	*	--	*
FC vs. FEN, FEC	--	--	--	--	--	--
FEN vs. FEC	--	--	*	--	--	--

[a] Significant F values; **(.01); *(.05).

[b] Orthogonal contrasts; **=.01; *=.05.

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Table 5. October biomass for Tristis (NC-5260) and Eugenei (NC-5326) cuttings rooted under the following soil treatments: 1) fumigated soils that were a] inoculated with an endomycorrhizal fungus (FEN), b] inoculated with an ectomycorrhizal fungus (FEC), or c] uninoculated (FC); or, 2) unfumigated soils with natural inoculum (UF).

	Hardwood Cutting Dry Weight (g)	New Stem Material Dry Weight (g)	Root Dry Weight (g)	Total Dry Weight Minus Leaf Weights (g)
Clone				
NC-5260	11.8	16.4	11.3	39.5
NC-5326	10.2	18.4	7.4	35.2
Treatment				
UF	10.8	14.9	8.7	34.1
FC	11.2	18.9	9.5	39.8
FGF	10.7	16.7	8.7	35.5
FPT	11.4	18.4	10.3	40.0
Significance[a]				
Clone	*	--	*	*
Treatment	--	*	*	*
Contrasts[b]				
UF vs. all	--	*	*	*
FC vs. FGF, FPT	--	*	--	--
FGF vs. FPT	--	*	*	*

[a]Significant F values; * = .05.

[b]Orthogonal comparisons; * = .05.

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population of microorganisms in the UF soil, which put a greater symbiotic and pathological demand on the cuttings. There may also have been a competition effect from the weeds growing in the boxes. A similar response was observed for stem and root dry weights. Fumigation increased growth by 8 to 30%. The FGF treatment produced the second smallest trees, and there was little difference between the FPT- and FC-treatment trees. This result is evidence that the ectomycorrhizal development had no biological impact on the trees. As seen in other studies, smaller trees for the mycorrhizal treatments are the common occurrence under moderate to high phosphorus fertility. We believe this phenomenon is due to the preferential reallocation of photosynthates from the tops to the roots during the establishment of the mycorrhizal symbiosis.

Clonal Responses

'Tristis' grew rapidly early in the season, whereas 'Eugenei' put on extensive growth later in the growing season. At the August 15th measurement date, Tristis had put on significantly more height and diameter growth than Eugenei. However, by October 15th, Eugenei had equalled and surpassed the height growth and put on significantly more diameter growth than Tristis. For the most part, Tristis had put on all its growth by August 15, although there was a small amount of growth after that date.

Eugenei's growth continued over the whole growing season. When compared with Tristis, it retained its leaves for a much longer time. Although Tristis had significantly more leaves than Eugenei on August 15th, there was no difference in the total leaf area between the two clones because Eugenei's leaves were larger. By October 15th, Tristis had shed all its leaves while Eugenei still retained some near the top of the shoot. The parents of Tristis come from more northerly latitudes than Eugenei. Perhaps this is why Tristis is more sensitive to the early shortening of the seasonal photoperiod.

In terms of total biomass response, Tristis outgrew Eugenei (Table 5). Although the hardwood cutting weights at the end of the study were slightly heavier for Tristis, there was no difference in new stem growth produced on the cuttings. Leaf dry-weight comparisons could not be made because of our sample dates, but it seems likely that there was little difference in total mass of leaves produced by either clone. The major difference between clones in biomass occurred in root growth. The average Tristis tree produced almost 4g more root dry weight than did Eugenei. This response is of special interest when comparing the mycorrhizal responses of the two clones during the establishment year.

Mycorrhizal Responses

Eugenei trees produced more ecto- and endo-mycorrhizae than did Tristis (Table 6). For example, Eugenei had 63% of its fine roots infected in the FGF treatment and 52% in the UF treatment. This infection compares with 23% and 39% respectively, for Tristis. The observed infections suggest that Eugenei had a greater affinity for GF than for the native fungi in the UF treatment, whereas the reverse is the case for Tristis. The larger root system of Tristis also suggests that this clone exploited the soil profile more completely and therefore did not gain the same advantages from the mycorrhizal symbiosis than did Eugenei with its smaller root system. The ectomycorrhizal response of the two clones was not as clear. Upon close examination, only one site of ectomycorrhizal infection was found on any of the root samples. Fifty-seven percent of the Eugenei trees had one infection site, compared with 43% of the Tristis trees. Even for the ectomycorrhizal case, Eugenei had a greater percentage of trees infected than did Tristis. It seems that the minimal ectomycorrhizal infection had no biologically significant impact on the cuttings. However, ectomycorrhizal plants were generally 10 to 15% heavier than were endomycorrhizal plants. This growth difference probably is not the result of PT stimulation, but, rather, a lack of response to the symbiosis.

The results of this study are similar to those found in other experiments. Both clones will form endomycorrhizae, but both also seem to be capable of autotrophic growth. It seems that, under the phosphorus levels of this study (35mg/l Bray 1 extractable P), the trees do not form many mycorrhizae. However, at similar phosphorus levels, many other species do form extensive mycorrhizal root systems (Schultz et al., 1982). Before it can be stated that these clones are definitely capable of autotrophic growth, growth comparisons at different phosphorus levels must be made. Although neither clone showed much development of ectomycorrhizae with PT, the literature suggests that Tristis may have a greater selectivity for ectomycorrhizal development than does Eugenei.

Table 6. Mycorrhizal development in Tristis (NC-5260) and Eugenei (NC-5326) cuttings rotted in unfumigated soils with natural inoculum or fumigated soils inoculated with endo- or ecto-mycorrhizal fungi.

	% of Roots Infected			% of Trees with 1 infection site
	Unfumigated		Fumigated	
Clone	Endo	Ecto	Endo	Fumigated-Ecto
NC-5260	39	0	23	43
NC-5326	52	0	63	57

CONCLUSIONS

Populus hybrids show extensive selectivity in mycorrhizal formation. This selectivity should be identified for the most important clones available so that proper inoculum can be used in producing propagules. In addition, cultural practices, such as site preparation and weed control with herbicides, can influence the available inoculum on a planting site. Although some hybrids seem to show autotrophic growth without mycorrhizal development at relatively low available soil phosphorus levels, the potential for mycorrhizal formation should be established for all hybrids.

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EFFECT OF *ALNUS GLUTINOSA* ON HYBRID *POPULUS* GROWTH AND SOIL NITROGEN CONCENTRATION IN A MIXED PLANTATION

Jeffrey O. Dawson and Edward A. Hansen[1]

Abstract.--Height growth of hybrid *Populus* and soil nitrogen concentration around *Alnus glutinosa* stems differed significantly both spatially and with the *Alnus*/*Populus* mixture in a short-rotation intensively cultured mixed planting. *Populus* height growth comparable to that obtained from optimal rates of ammonium nitrate fertilization occurred where *Alnus* rows were directly adjacent to *Populus* rows and where *Alnus* comprised about 66% of the mix. Soil nitrogen concentration around *Alnus* was greatest where *Populus* rows were directly adjacent to *Alnus* rows. Results are consistent with speculation that stress on young *Alnus* induced by competition from more rapidly growing *Populus* resulted in rapid accretion of nitrogen in soil.

Poplar (*Populus*) plantations under intensive cultural conditions use large quantities of nitrogen. Aboveground components of young poplar plantations may take up as much as 90 kg/ha/yr (Hansen and Baker 1979). The possibility of using nitrogen-fixing trees to supply nitrogen has been extensively discussed (McIntyre and Jeffries 1932, Finn 1953, Red'ko 1958, Tarrant 1961, Dale 1963, DeBell and Radwan 1979, Gordon and Dawson 1979). Among the most intensively studied silvicultural systems that take advantage of nitrogen-fixing trees are mixed plantations of alders (*Alnus*) and hybrid poplars (Tarrant and Trappe 1971, DeBell 1975). Both alders and poplars have wood properties acceptable for chip and fiber products.

Published results by Zavitkovski and others (1979) show that height growth of trees incapable of symbiotic N_2 fixation decreases with distance from N_2-fixers for a number of species. Therefore, the spacing of N_2-fixing nurse trees in relation to associated trees needs to be considered if mixed plantations are to be efficient.

Another consideration when designing mixed plantations is the amount of N supplied by the N_2-fixers compared with the N demand of associated plants. Some of the probable factors affecting N supply by N_2-fixers to a mixed plantation are the percentage of N_2-fixers in the mix, the N_2-fixation rate, and the availability of N to the associated trees.

It is well documented that trees incapable of N_2 fixation usually show increased growth when mixed with N_2-fixers. Height and diameter growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were greater in plantations containing 59 percent red alder (*Alnus rubra* Bong.) than in pure plantations (Tarrant 1961, Miller and Murray 1978). In a 2-year coppice rotation, height and diameter growth of black cottonwood (*Populus trichocarpa* Torr. & Gray) were greater in stands containing 50 percent red alder than in pure stands (DeBell and Radwan 1979). Total yield of the mixed planting was about 50 percent greater than that of either species planted alone. Heights of several conifer and hardwood species (including *Populus*) increased from 4 to 50 percent when European black alder (*Alnus glutinosa* (L.) Gaertn.) was interplanted as a 50-percent mix (Dale 1963, Plass 1977). An underplanting of

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European black alder accelerated both height and diameter growth of *Populus* (Van der Meiden 1961). These studies demonstrate that *Populus* will grow faster when planted with *Alnus* than when planted without, and that in some cases total yield is increased. However, the percentage of a N_2-fixer in mixed plantings necessary to promote optimal growth of an associated species has not been addressed.

In our studies, the influence of *Alnus* and hybrid *Populus* mixture on *Populus* height growth and soil N concentration around *Alnus* were investigated over a range of mixtures in a short-rotation intensively cultured plantation at Rhinelander, Wisconsin (Hansen and Dawson 1982, Dawson and others 1983). Results of these studies are summarized in this report.

METHODS

A 30 x 30 m plot at the Harshaw Forestry Research of the U.S. Forest Service, North Central Experiment Station, near Rhinelander, Wisconsin was planted in May of 1977. Planting stock consisted of 1-year-old, bare-root seedlings of an unknown seed source of *A. glutinosa* from a commercial nursery and greenwood tip cuttings of *Populus* rooted the previous fall in a "Jiffy-7" peat pellets. The *Populus* consisted of an inadvertent mixture of two hybrid clones: *P. betulifolia* x *P. trichocarpa* Torr. & Gray and a *Populus* clone of indeterminate origin. The trees were spaced at 1.2 x 1.2 m in 26 rows with 26 trees per row. Each row was planted with either alder or poplar. The mix of taxons graded from four consecutive poplar rows on one side of the plot through increasing frequency of alder rows to four consecutive rows of alder on the opposite side of the plot. Rows planted with alder were numbers 1, 2, 3, 4, 6, 7, 8, 10, 11, 13, 18, and 22.

The soil was a silt loam of the Padus series overlying sand and gravel at depths of 30 to 60 cm. The site was plowed to a depth of 16 cm, disked, and harrowed prior to planting. Soil samples were taken at 4-cm depth intervals to 16 cm in the plow layer of this soil and analyzed for total Kjeldahl nitrogen. Weeds were controlled with a combination of mechanical and hand cultivation and directed herbicide spray.

An irrigation gradient was superimposed on the plot at an angle of 90 degrees to the alder/poplar gradient. Analyses showed little evidence of interaction between irrigation and the species or clonal mixtures.

Tree heights were measured at the end of each growing season for 3 years. Diameters (15 cm above the first year's terminal bud scar) were measured at the end of the second growing season only. The relation of *Populus* height growth to the presence of *Alnus* was analyzed by regression. The dependent variable was the mean tree height in each *Populus* row. The independent variables were distance from a given *Populus* row to the nearest *Alnus* row and the percent of *Alnus* within various distances of the *Populus* row. Because of the planting design used, the percent of *Alnus* varied with distance from the *Populus* row. Consequently, distances of 2.4, 4.9, and 6.1 m either side of the *Populus* rows were selected to determine the "percentage of *Alnus*" that related best to *Populus* growth.

The roots of three alder trees in the *Alnus*/*Populus* mixed planting were excavated during their second growing season. A piece of root with attached nodules was removed from each tree and immediately assayed for nitrogenase activity. For the assay, root incubation techniques described in Dawson and Gordon (1979) and a portable gas chromatograph for the acetylene reduction assay (Mallard and others 1977) were used. The assay was performed to confirm N_2-fixation by *Alnus* nodules in the field plots of the study.

The plantation was coppiced after the third growing season and aboveground tissue was removed from the site. Soil samples were taken in spring following the fourth growing season. Three interior *Alnus* trees in each of rows 7, 11 and 15 were randomly selected as foci for soil sampling. Row 7 had *Alnus* rows on either side, row 11 had a row of *Populus* on one side and a row of *Alnus* on the other, while row 15 had rows of *Populus* on either side. Soil samples were taken with a soil probe adjacent to an alder stem and at 15, 30, 45, and 60 cm distances at a randomly selected azimuth for each distance from a stem. The probe samples were taken to a depth of 16 cm and divided into 4-cm depth increments. Soil samples were oven dried at 70°C and sieved through a 2-mm mesh screen prior to soil nitrogen determination using a micro-Kjeldahl procedure. An ANOVA was performed using a nested design to determine the variation in soil nitrogen concentration around *Alnus* stems associated with composition of adjacent rows of trees, depth of soil sample, and distance of sample from alder stem. Nitrogen concentrations from the same distance from stems within sample rows were compared with soil nitrogen concentrations from corresponding depths prior to tree planting using a t-test.

RESULTS

Height of Populus increased with increased Alnus in the mixture and with proximity to the nearest Alnus row. The maximum Populus height occurred in the area of the plot with the highest proportion of Alnus. This Populus row (row 9) was bounded on either side by Alnus, which constituted 66 percent of the mixture for a 4.8-m-wide strip. Average height of 3-year-old Populus in row 9 was 4.9 m (21 percent higher than the Populus in rows 25 and 26). Another single Populus row (row 5) had an anomalous low height. Consequently, this low value was discarded from Populus growth analyses. Alnus height growth was considerably slower, averaging only 55 percent of the average of all Populus at the end of 3 years (2.5 vs. 4.5 m).

Coefficients for regressions show that in a 3-year-old plantation, Populus height increases with increasing Alnus in the mixture and decreases with distance the Populus is from the Alnus. Both independent variables were significantly related to Populus height growth ($P = 0.05$).

Other regressions were run to test for possible bias from the Populus clonal mixture and for possible plot border effects. Although there was no noticeable height growth difference between the two Populus clones at the end of the second year, there was a significant height difference between them at the end of the third year. Also, the two clones were not randomly distributed over the plot but tended to be segregated by rows. Consequently, the mean row tree height was adjusted by an amount that depended on the relative proportion of the two clones in the row and the ratio of the average height of each clone. However, analysis using unadjusted data still resulted in R^2 values of 0.85 to 0.88, and deletion of all Populus rows containing some of both clones (rows 9, 21, 23, 25 and 26) resulted in R^2 values of 0.92 and 0.98. Therefore, it seems that although the mixture of two Populus clones complicated the analysis somewhat, it did not change the interpretation of the results. In all cases the two independent variables, distance and percent Alnus, were significant regardless of the order in which they were entered into the equation, and the model had a consistently good fit as evidenced by the high R^2.

It is apparent that Populus height growth decreases sharply near the plot border. To test whether plot border effects were unduly influencing the model, regressions were run using adjusted clonal height data and deleting the three border rows (rows 24, 25, and 26). The effect on the model of deleting the three border rows was minor; R^2 values still ranged from 0.83 to 0.92.

Since diameter growth of the two Populus clones was markedly different throughout the study, diameter was not used as a variable to test treatment response. However, since both diameter and height of Populus were related similarly to Alnus, it follows that proximity to Alnus increases Populus biomass as well as height growth.

The three samples of root nodules assayed were capable of reducing acetylene to ethylene, indicating nitrogenase activity and, thus, N_2-fixing capability of the planted A. glutinosa.

Soil nitrogen concentration in the top 16 cm of soil at this study site prior to planting was uniform with no significant differences among depths and little variation among samples from the same depth. Soil nitrogen concentrations of the plow layer before planting were 966 mg/kg dry weight in the top 4 cm of soil, 986 at the 4-8 cm depth, 962 at the 8-12 cm depth, and 888 at the 12-16 cm depth.

Analysis of variance revealed highly significant differences in total soil nitrogen concentration after 3 years around Alnus stems ($\alpha = 0.0009$) and these differences were associated with composition of rows adjacent to alder. Levels of total nitrogen concentration were highest where the Alnus was bracketed by Populus, and showed a 13 percent increase in soil-nitrogen concentration over levels measured prior to planting. Soil nitrogen concentration was only 1 percent higher than initial levels where alder had an adjacent row of poplar and an adjacent row of alder. Soil nitrogen concentration was lowest, with a significant net nitrogen loss of 10 percent where alder was associated with rows of alder on either side.

Soil nitrogen concentration around alder stems also varied significantly by depth ($\alpha = 0.0001$). Nitrogen concentration was highest in the top 4 cm of soil. Significant losses in soil nitrogen from the continuous Alnus strip were greatest at depths from 4-12 cm.

The distance from the alder stem at which soil samples were taken was not associated with significant change in soil nitrogen

concentration. There was no significant interaction between composition of adjacent rows and distance from alder stem.

DISCUSSION

A contiguous plot of pure Populus (same two clones as in the mixed plot) was fertilized annually with a gradient of NH_4NO_3. It was therefore possible to compare height growth response in fertilized Populus with that in an Alnus/Populus mixture. Since the plot treated with commercial fertilizer was planted earlier (August 1976 compared with May 1977 for the Alnus/Populus mixture), the tree heights of the mixed plot were adjusted upward by assuming that the untreated control portions of each plot (rows 24-26, which had no fertilizer or contained no Alnus) would have otherwise had equal height growth. This assumption resulted in increasing the tree heights of the mixed plot by 0.2 m. At the end of 3 years, maximum Populus height from commercial fertilizer was 5.25 m, compared with about 5.10 m for the adjusted heights from the mixed plot. Thus, the height difference between the two treatments was 0.15 m or 3 percent greater in the commercial fertilizer plot. If the difference in planting date were ignored, the height growth difference at 3 years would be 0.35 m or 7 percent.

Although more Alnus was better from the standpoint of Populus growth, Alnus growth lagged considerably behind that of the Populus. Similar results with European black alder and hybrid poplar have been reported by Wittwer and Immel (1977) and for red alder and black cottonwood by Harrington and others (1979). It was evident in this study that single rows of Alnus would soon be completely shaded by the Populus and perhaps eventually eliminated from the mix. It appears that Alnus may have difficulty surviving when mixed with Populus except perhaps for shorter rotations such as the 2-year coppice tested by DeBell and Radwan (1979) or on sites relatively favorable to Alnus (Harrington and others 1979). One strategy might be to interplant Alnus with the realization that it may be suppressed and eliminated from the plantation before harvest. There is also the possibility that Alnus growth can be substantially improved by selection and breeding. A series of sequential selections of Alnus glutinosa grown from seed in a greenhouse study resulted in the identification of fast-growing Alnus clones that performed as well as a fast-growing Populus clone in a controlled environment optimized for hybrid Populus (Bajuk and others 1978).

Alnus in this study was effective in symbiotically fixing N_2 as demonstrated by acetylene reduction ability and the zones of soil N accretion around some individual Alnus stems.

One apparently anomalous finding was that a row of poplar with many rows of nitrogen-fixing alder on either side did not grow as rapidly as Populus intermixed with Alnus. This led us to investigate the effects of hybrid poplar on the accretion of nitrogen in soil around alder stems. Since alder height growth at the end of three years in this plantation averaged 45 percent less than poplar height growth, and since relative growth rates remained constant after coppicing, the alder was shaded by the poplar at least during the 3 years prior to the time of our soil sampling. Some alder mortality was occurring in the fifth year of growth in single and double rows of alder. This shading may have resulted in tissue death and decay with release of N into soil. Similarly, input of nitrogen from tissue killed by poplar allelochemicals is possible. Younger and Kapustka (1982) note an allelochemic effect of Populus tremuloides Michx. on nitrogen fixation by Alnus rugosa (Du Roi) Spreng. in northern Wisconsin, and work in progress at the Forestry Department of Laval University in Quebec City indicates that phenolic acids present in leaf or bud leachates and extracts of Populus balsamifera L. are inhibitory for the juvenile development of Alnus crispa var. mollis Fern. (Thibault, personal communication). The competitive factors of shading and possible allelopathy due to poplar in our plantation study cannot be excluded as causes for early nitrogen accretion in soil around alder grown in close proximity to hybrid poplar. Leaf, twig, nodule, and fine-root tissue sloughed from plants would occur in highest quantities near the soil surface, perhaps explaining the significant differences in soil nitrogen concentration associated with depth of soil sample.

Hansen and Dawson (1982) found that localized regions of soil nitrogen accretion occurred within 15 cm of stems and in the top 4 cm of soil in a 2-year-old, 1 x 1-m plantation of A. glutinosa. This pure alder plantation consisted of clones that suffered severe frost damage. However, soil sampled away from this localized zone showed a net decrease in total soil nitrogen concentration. This localized pattern of soil nitrogen accretion conformed to the zone of maximum root activity in the 2-year-old plantation. Alder roots and soil nitrogen accretion are more extensive in the upper soil stratum of the

4-year-old plantations in this study, consistent with the differing results. Recent measurements in a 3-year-old *A. glutinosa* plantation growing vigorously in a well-drained terrace site in southern Illinois revealed no net increase in soil nitrogen concentration (Dawson, unpublished). Gadgil (1971) subjected nitrogen-fixing lupine plants to shading and defoliation stress in greenhouse experiments. The results suggested that damage to lupine plants could increase nitrogen availability to *Pinus radiata* seedlings planted in the same substrate. These observations lend support to the suggestion that early soil nitrogen accretion around nitrogen-fixing *A. glutinosa* may be related to plant stress.

Nitrogen losses from soil around alder planted in contiguous rows may be due to the retention of symbiotically fixed nitrogen by alder in growing tissue together with a net uptake of combined nitrogen from soil by alder. When soil is plowed, oxygen diffusion into soil is facilitated, thereby increasing the potential for nitrification by soil bacteria. Nitrate resulting from this aerobic process is readily leached out of surficial soil. Where this loss is not balanced by nitrogen inputs, such as those from nitrogen-rich alder litter and sloughed root tissue, net losses are easily possible. Bollen and Lu (1968) found high nitrification rates in red alder stands. Increased nitrification could have resulted in both increased leaching loss and increased uptake of nitrate with increased percentages of alder in our mixed planting. The effects of coppicing and irrigation in this study on alder root dynamics and nitrogen transformations in soil are not known. Further study will be required to explain fully the differences in soil nitrogen that we found.

We conclude that the configuration of mixed alder/poplar plantations is important if an early increase in potential nitrogen fertility of soil is expected. We also suggest that stress may precipitate early input of nitrogen into soil around nitrogen-fixing trees. Thus early nitrogen input may be inconsistent with greater longterm inputs of nitrogen where nitrogen-fixing nurse trees are completely inhibited or eliminated in young mixed plantations.

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DEVELOPING ALNUS FOR USE IN INTENSIVE CULTURE[1]

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Abstract.--Provenance tests and one clonal test have been analyzed to provide guidelines for the continuing efforts on the genetic improvement of Alnus. Observations also are made on the need for experiments with other silvicultural alternatives that might be applied to the intensive culture of alders.

Introduction

Alnus was among the first genera to be recog-
zed as having the potential for intensive culture
ickman 1975). This promise was based both on
owth and yield properties and the ability of ald-
s to symbiotically fix nitrogen. In the Pacific
rthwest, Alnus rubra has proved to be a leading
ndidate for intensive culture, both in pure
ands and in mixture with Populus trichocarpa
eBell and Radwan 1979; Harrington et al. 1979).
the eastern United States the value of Alnus for
tensive culture is less certain at this time. No
eld data on large, pure alder plantings have been
veloped. The nitrogen-fixing ability of Alnus in
xture with Populus has been established, but the
ck of height growth compatability (Hansen and
wson 1982) and potential allelopathic relation-
ips (Dawson et al. 1983) in such mixtures have
lled this approach into question. Mixtures with
her species have shown some promise (Plass 1977;
ttwer and Immel 1977) but have not been evaluated
much detail.

One major limitation in evaluating the contri-
tion that Alnus can make to intensive culture in
e north central United States has been the lack
identified selections, preferably clones, that
uld be relied on to perform well. There are no tree-form alders native to the eastern United States, so interest has centered on exotics; Alnus glutinosa in particular (Hall and Maynard 1979). Genetic evaluation of Alnus glutinosa in this country began with Funk's (1973, 1979) test of 15 provenances on strip mine spoils in Ohio. In 1976, we began collecting additional Alnus seed sources. In 1979, we established new test plantations to augment Funk's study, both in terms of the range of germplasm evaluated and the types of U.S. sites considered (Robison et al. 1978). This paper will review the results from the first four growing seasons of those tests and from some related studies to provide an assessment of the potential of Alnus for intensive culture and to recommend the continuing steps needed to develop the best genetic material for this use. Information on general approaches to the genetic improvement of Alnus also has been given in two previous papers by our group (Hall and Maynard 1979; Robison and Hall 1981).

Materials and Methods

Most of the data reported in this paper were collected as part of our annual fall measurements in two provenance plantings, one located on the U.S. Forest Service's Harshaw Farm in northern Wisconsin, the other on Iowa State University's Rhodes Farm in central Iowa. The detailed descriptions of these planting sites, establishment procedures, and the experimental design of the plantations has been reported elsewhere (Maynard and Hall 1980). In addition to the A. glutinosa provenances that were the main focus of these tests, the plantation at Harshaw included several other alder species planted in the border rows. This included one Italian and one Belgian seed orchard collection of A. cordata, one Czechoslavakian and one Netherlands provenance of A. incana, one Idaho source of A. rubra, and one hybrid progeny of A. incana X A. glutinosa produced in Finland. At the beginning

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of the second growing season at Harshaw, 82 A. incana plants from the Netherlands provenance were used to plant in gaps in the original plantation where tree mortality had occurred. Comparative data for Populus clones grown under similar field conditions at the Harshaw farm were supplied by Dr. E. A. Hansen of the U.S. Forest Service.

Each fall, the Rhodes plantation was evaluated for the production of flower buds. Based on the 1982 data, a comparison was made between flowering and nonflowering trees in those provenances in which several trees were flowering to detect any relationship of flowering to total tree height and to height growth during the 1982 season. The provenance test was analyzed as a split-plot design using the mean values for flowering and nonflowering trees on each plot.

To evaluate the performance of clonal selections, another test plantation was established at the Rhodes Farm in June 1981. Selections of good and poor phenotypes were made in older alder plantations in Ohio (Funk 1973, 1979) and Illinois (Phares et al. 1975). Six additional clones identified in a greenhouse growth experiment (Bajuk et al. 1978) were included, as was the clone of one exceptionally fast-starting border tree in the Rhodes provenance plantation. Rooted cuttings were produced from greenhouse stock plants (Hall and Maynard 1979) and were planted on a 1.5 m square spacing in a randomized complete block design with 10 trees per clone. In the fall of 1982, after two growing seasons, heights and diameters of the trees were measured, and the presence or absence of flowering was noted. Diameter measurements were taken near ground level at the point of minimum diameter between the lowest branch and the swelling of the root collar.

Age-age correlations were developed from two sets of data; the 4-year results of the Harshaw and Rhodes provenance tests and from stem-analysis data from 17-year-old trees harvested in Funk's (1973, 1979) Ohio provenance trial. The stem analysis was based on disks cut at 1.0 m intervals along the stem. A computer program was used to convert ring count and width measurements into estimated heights and volumes by years. Correlations were calculated based on individual tree values for both the provenance test data and the stem analysis data.

Genotype by environment (G x E) interactions were estimated by measuring a subset of 17 provenances growing at three locations: the Rhodes and Harshaw plantations and a plantation near the town of Humm Wye in southern Illinois. The Humm Wye planting was made in 1980 by the Forest Service on a level bottomland site with a spacing of 1.8 m by 3.0 m. There were eight trees per plot and four replications with the same 48 provenances included in the Iowa and Wisconsin tests. First-year measurements of survival and height growth at the Humm Wye planting were provided by Dr. Knud Clausen of the U.S. Forest Service. Height and diameter measurements at a height of 1.0 m were taken in July 1982 on all three plantations. A combined analysi[s] of variance was computed for the three locations t[o] estimate the statistical strength of the G x E interaction (Comstock and Moll 1963). Variance co[m]ponents also were estimated so the main effects of provenance and location and the G x E interaction could be expressed as a percentage of total phenotypic variation (Cockerham 1963).

The general linear model of the Statistical Analysis System (Helwig and Council 1979) was used in the computation of all provenance and clonal means, analyses of variance, and variance componen[t] estimates.

Results and Discussion

Table 1 summarizes the year by year height growth performance in the Iowa and Wisconsin plantations and shows a comparison with one of the better Populus clones grown at the same location i[n] Wisconsin. As previously reported, the first-year survival in both plantings was 90 percent or bette[r]. At the end of four growing seasons, survival still was 83 percent at both locations. Because of the stump sprouting ability of Alnus few trees died completely even though many southern sources had suffered repeated winter dieback. In the 1980 establishment of the southern Illinois plantation, a summer drought period did cause up to 88 percent mortality of some of these same provenances. Southern provenances had the best first-year survival (up to 88 percent) under those stress conditio[ns].

By selecting the best provenances it would see[m] that first year height growths of 0.5 to 0.8 m could be achieved. However, herbaceous competitio[n] seems to thrive around the base of young alders, and the tendency of alders to produce many low branches in their first year makes chemical contro[l] of these weeds difficult. Therefore, alternative methods of producing alder planting stock should b[e] sought that will give better first-year growth potential to keep pace with associated trees such as Populus hybrids and ahead of the weed competition. This study utilized 3- to 4-month-old containerize[d] planting stock (Maynard and Hall 1980). One promising alternative that should be considered is 2-0 nursery stock.

After establishment, the best alder provenance[s] were capable of making about 1 m of additional height growth each year at Harshaw. This growth rate places the alder progressively further behind the height growth of the better Populus clones. In Iowa, the annual height growth varied widely, depending on weather conditions. In 1980 and 1981, which were drier years, the best provenances were not capable of growing more than 0.75 m in height. But in 1982, a year with abundant moisture, all trees averaged 1.5 m of height growth, and the best trees grew 2 m. This indicates that height growth of A. glutinosa will fluctuate widely, depending o[n] moisture status in a given year. Presumably, grow[th] on sites of different water-holding capacity

Table 1. Overview of growth by year and location. Populus data are for plots on the same farm, but for the years 1980, 1978, 1979, and 1980, respectively.

	Rhodes, Iowa			Harshaw, Wisconsin			
		Average Growth (cm)			Average Growth (cm)		
Year	Conditions	All Trees	Best Prov.	Conditions	All Trees	Best Prov.	Populus Clone 5262
1979	Established in late May	63	84	Established in mid June	33	48	97
1980	Canker disease problems	48	70	"Normal"	74	101	105
1981	Dry spring and summer	38	75	"Normal"	69	110	157
1982	"Harsh" Winter Abundant summer moisture	153	199	Late frost followed by canker problems	40	94	231

ould be similarly affected. Another factor that ay have contributed to the 1982 burst of growth at ne Rhodes plantation was the crown closure, and ubsequent elimination of understory competition, nat occurred in the plots with larger trees.

Table 2 lists the 4-year height growth and ankings by height growth of the individual proveances at the Iowa and Wisconsin test sites. At nis stage (age) of development, the best proveances for use in Iowa come from scattered areas, rimarily in central Europe: central and southern ermany, Hungary, Ireland, the Netherlands, and Denark. The last two provenances may represent econdary sources that originally were introduced rom other areas of Europe. Superior performance the Wisconsin site was restricted to a more georaphically confined set of provenances from northrn and eastern Europe: Poland and the Baltic tates. These results are consistent with those of unk (1979) in his earlier provenance test, but they ave the value of extending our knowledge of the ariation patterns and identifying sources of superor germplasm outside the geographic region sampled Funk. Patterns of climatic suitability have been vident from the beginning of the second growing eason (Maynard and Hall 1980). Some additional inter damage has occurred in southern provenances ince that report; e.g., provenance 962 from northrn Italy has been surpassed in the Iowa plantation more hardy provenances because of low-level damge it has suffered in the last 2 years. Because uch marginally adapted provenances still should ave considerable value in an interprovenance breedng program, preparing for the next cycle of selecion by identifying useful provenances at the end f 2 years probably is warranted.

In addition to the overall growth patterns, ome other potentially useful traits have been noted in these studies. The provenances from the southeastern portion of the A. glutinosa range (800 numbers) produce much larger leaves and the best annual growth rates. Mediterranean provenances (numbered in the 900's) tend to produce a fine, upright branch structure. If these traits could be combined with the coldhardiness of the more northern provenances by breeding, it could lead to substantial improvements for total growth, form, and type of biomass produced. Another important trait is likely to be resistance to the Phomopsis-like canker that has been observed in these tests and by other researchers (Oak and Dorset 1981). On the basis of observations to date, it is not certain that any provenance is totally immune to the disease, but all provenances do produce individuals that have some resistance and/or ability to recover. Outbreaks of the canker have followed periods of heat, drought, or frost stress in the plantations, and genetic variability in canker resistance might trace back to a genotype's response to those stresses.

To expand our knowledge of G x E interactions the height and diameter rankings of 17 provenances were analyzed across a north/south transect represented by the northern Wisconsin, central Iowa, and southern Illinois plantations. The results are given in Table 3. Provenance rankings for both height and diameter tend to follow the same pattern. Northeastern provenances such as the Polish sources 561, 541, and 511 rank best in Wisconsin, but fall consistently in rank in the two more southern test sites. This change is even more striking for the Baltic and Scandinavian provenances (Table 2). Actual height growth is as good or better at the southern test sites, but other provenances benefit more from the longer growing seasons, milder winters, etc., and surpass the northern sources in rank. For example, southern provenances such as the French 682 and Italian 962 improve their ranking considerably

Table 2. Average 4-year heights of Alnus glutinosa grown at two locations.

Provenance Number	Geographic Origin	Latitude (North)		Avg. Height in cm (Rank) Rhodes, IA		Harshaw, WI	
118	Coote Hill, Ireland	54	5	374	(6)	252	(15)
127	Bandon, Ireland	51	46	310	(26)	225	(24)
131	Golspie, Scotland	58	15	233	(38)	202	(32)
151	Innerleithen, Scotland	55	38	324	(21)	205	(31)
172	Wrexham, N. Wales, U.K.	52	57	332	(18)	243	(18)
211	Oslo, Norway	59	40	213	(41)	218	(27)
213	Burgen, Norway	60	16	177	(42)	156	(37)
216	Steinkjer, Norway	64	12	121	(48)	147	(38)
221	Humieback, Denmark	56	0	411	(1)	241	(19)
222	Sakskobing, Denmark	54	45	292	(31)	218	(28)
261	Turku, Finland	60	25	146	(47)	164	(34)
281	Tartu, Estonia, USSR	58	10	318	(24)	270	(6)
291	Riga, Latvia, USSR	56	44	266	(34)	267	(7)
431	Uetze, W. Germany	52	25	376	(4)	245	(17)
451	Kinzig River, W. Germany	50	0	298	(30)	252	(14)
472	Offenburg, W. Germany	48	30	366	(9)	229	(23)
481	Ingolstadt, W. Germany	49	0	374	(7)	249	(16)
511	Naklo, Poland	53	8	368	(8)	273	(5)
541	Brzeziny, Poland	51	48	306	(27)	297	(3)
542	Bialowieza, Poland	52	30	299	(29)	289	(4)
561	Lezajsk, Poland	50	0	330	(19)	330	(1)
562	Bresesko, Poland	49	50	321	(22)	267	(8)
571	Kosteler, Czechoslavakia	50	1	352	(13)	300	(2)
582	Zvolen, Czechoslavakia	48	35	319	(23)	257	(12)
591	Gyor, Hungary	47	40	389	(3)	260	(11)
592	Kormend, Hungary	46	55	395	(2)	225	(25)
614	Scherpenzeel, Netherlands	52	50	375	(5)	234	(21)
633	Zurich, Switzerland	47	16	282	(33)	236	(20)
638	Lausanne, Switzerland	46	32	362	(11)	256	(13)
653	Nancy, France	48	48	332	(17)	213	(30)
682	St. Julien en Born, France	44	4	352	(14)	166	(33)
722	Novoselec, Yugoslavia	45	35	356	(12)	261	(10)
724	Durdevac, Yugoslavia	46	5	328	(20)	229	(22)
792	Sofia, Bulgaria	43	0	315	(25)	266	(9)
795	Klisura, Bulgaria	42	45	336	(15)	224	(26)
704	Kosti, Bulgaria	42	3	303	(28)	214	(29)
841	Sochii, USSR	43	36	250	(35)	106	(44)
843	Yalta, USSR	44	40	336	(16)	159	(36)
801	Hashtpar, Iran	37	30	170	(43)	73	(48)
803	Noor, Iran	36	35	157	(45)	96	(47)
911	Zamora, Spain	41	11	167	(44)	99	(45)
912	Pontevedra, Spain	41	52	154	(46)	99	(46)
962	Pordenone, Italy	46	2	364	(10)	161	(35)
973	Pinaura D. Lucca, Italy	43	49	226	(39)	146	(40)
975	Villa Basilica, Italy	43	48	285	(32)	146	(39)
981	Cosenza, Italy	39	10	219	(40)	109	(43)
985	Forli Del Sannio Is., Italy	41	39	249	(36)	130	(42)
901	Lamja, Greece	38	54	240	(37)	138	(41)

in comparing the northern to southern test sites. We have previously noted the wide differences in seasonal bud set behavior between northern and southern provenances (Maynard and Hall 1980). In a recent analysis of data on a subset of these same 48 provenances of A. glutinosa grown in Iowa, Wisconsin, Pennsylvania, and New Brunswick, similar north/south patterns were observed while east/west differences were not strong. For example, the correlation in first-year height growth for the trees grown in Iowa and Pennsylvania was 0.83 (DeWald 1982; DeWald et al. 1983). They also not[ed] that southern provenances suffered less growth lo[ss] when grown on droughty mine spoil sites.

Table 4 gives an analysis of the strength o[f] the genotype by environment interactions. For bo[th] height and diameter the interactions term is

Table 3. Provenance rankings within locations for height and diameter in July 1982. See Table 2 for meanings of provenance numbers.

	Height			Diameter		
Rank	Harshaw Wisconsin	Rhodes Iowa	Humm Wye Illinois	Harshaw Wisconsin	Rhodes Iowa	Humm Wye Illinois
1	561	592	962	561	592	962
2	541	614	592	541	614	722
3	511	591	481	591	481	481
4	722	481	722	511	591	592
5	591	962	614	722	722	451
6	481	511	682	724	962	682
7	451	722	511	633	511	511
8	633	561	451	481	795	795
9	614	795	724	592	724	714
10	724	682	795	451	561	633
11	131	724	591	795	682	591
12	222	451	561	614	541	614
13	592	222	633	222	222	561
14	795	541	975	131	451	222
15	682	633	541	962	131	131
16	962	975	222	682	633	541
17	975	131	131	975	975	975

Table 4. Combined analysis of variance to estimate the relative strength of provenance variation and genotype x environment interaction; based on 17 provenances measured at three locations in July 1982.

		Height		Diameter		
Source	df	MS	F	MS	F	Expected Mean Squares
Locations	2	28830		3.279		
Reps. (Loc.)	9	7002		0.915		
Provenances	16	11779	2.46*	1.443	2.37*	$\sigma^2_e + 3.9\ \sigma^2_{P \times L} + 11.7\ \sigma^2_P$
Provenances x Locations	32	4797	5.02**	0.608	3.13**	$\sigma^2_e + 3.9\ \sigma^2_{P \times L}$
Error	144	955		0.194		σ^2_e

	Estimated Value for Variance Component			Percent of Total Phenotypic Variance	
	σ^2_e	$\sigma^2_{P \times L}$	σ^2_P	$\sigma^2_{P \times L}$	σ^2_P
Height	955	989	595	39.0%	23.4%
Diameter	0.194	0.109	0.072	29.1%	19.2%

Significance of the F test shown as * = significant at the 0.05 probabliltiy level and ** = significant at the 0.01 level.

stronger than the provenance component. Therefore, we can conclude that the selection of Alnus in the north central United States, and probably its breeding as well, should be based on results at a number of geographically dispersed test sites. Recommendations for a specific area should be based on the most similar test site results and extrapolations from the other test sites. The three test sites discussed in this paper are separated by about 3.5 (Iowa/Wisconsin) and 4.5 (Iowa/Illinois) degrees of latitude. The east-west set of tests summarized by DeWald (1982; DeWald et al. 1983) cover an even greater span of mileage between test sites. This network probably is adequate for developing an overview of A. glutinosa performance in the region, but it is likely to miss some important variation related to local climates and, especially, sites.

To assess the progress in improving A. glutinosa for intensive culture, it is illustrative to return to a comparison with hybrid Populus clones. The mixed planting analyzed by Hansen and Dawson (1982) was grown at the Harshaw farm on a site very similar to the provenance test site. In the mixed planting, the average 3-year height of the alders was 2.5 m while the Populus hybrid clones averaged 4.9 m. In the provenance test, even the best provenances did not exceed an average height of 2.5 m at 3 years. However, as illustrated in figure 1, individual trees did exceed that height. The best 5 percent of the trees from the best provenances were more than 3.0 m tall. Hence, while the average performance of A. glutinosa provenances does not represent much hope for significant improvement, the range of individual tree variation should offer considerable raw material for a selection and breeding program. The Populus hybrids currently in use are the products of at least two stages of genetic improvement. Therefore, it is not surprising that one cycle of provenance selection in Alnus is insufficient to close the "improvement gap" between the two genera.

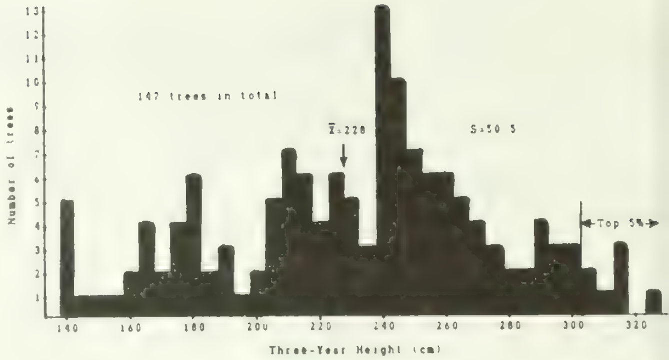

Figure 1. Frequency distribution of total 3-year heights for trees in the six best provenances grow at Harshaw, Wisconsin. Three trees that were less than 100 cm are not included on the graph.

Some data (Table 5) for other alder species are available from the unreplicated plantings of border and mortality replacement trees at the Harshaw site. Both the A. cordata and A. rubra plantings had poor growth and survival because of a lack of winter-hardiness. It is doubtful that sufficient hardiness can be found in these species to make them directly useful in the north central United States. Tests in more southern locations should be attempted. On the basis of the two provenances of A. incana that were studied, this species does show considerable promise and should receive more attention. The best trees in the Netherlands provenance were 0.5 m taller at three years than any of the A. glutinosa trees. A. accuminata from South America and several Asiatic Alnus species also may have value for use in the north central region (Hall and Maynard 1979) but no field tests have been conducted.

Just as hybrids have formed the basis of tree improvement in Populus, they may hold out the best

Table 5. Three year performance of other Alnus species at the Harshaw, Wisconsin, provenance test site.

Species	Number Planted	Number Surviving	Height (cm) Range	Height (cm) $\bar{X}$	Height (cm) S
A. cordata	40	3	16 - 57	31	-
A. incana					
Czech.	9	6	70 - 250	135	64
Neth.	82	58	35 - 380	211	84
A. incana x A. glutinosa (Finland)	19	7	27 - 157	92	53
A. rubra (Idaho)	11	0	-	-	-

ope for substantial improvements in Alnus (Hall nd Maynard 1979). The relatively poor performance Table 5) of the one hybrid tested probably is more eflective of the extreme northern origin of the arents than of the general value of the A. incana A. glutinosa cross. Hybridization work should roceed with parents that have been selected for ur latitudes and climates. Intraspecies crosses nvolving selected trees from diverse geographic rigins may also allow for the combining of desirable raits and give rise to heterotic growth. Such sys- ems are yielding very successful results in the opulus breeding programs in Europe.

One other feature of Populus tree improvement hat has yet to be applied in large scale to Alnus s the cloning of selected genotypes. Alnus clones an be established from greenwood cuttings (Hall nd Maynard 1979) or from tissue culture (Garton t al. 1981), but neither approach is efficient nough for large-scale use at this time. As noted n the last column of Table 6, no clone gave 100 percent survival of the 10 plants per clone set out in the experiment. Average survival was only 56 percent. This contrasts to the much better survival of seedlings that was discussed earlier, and it probably is related to the difficulty in getting a well-established root system on the cuttings before they are field-planted. In addition, rooting difficulties could be expected to contribute to the variation observed within and between clones. In general, the trees with better survival also ranked highest in growth characteristics (Table 6).

Table 6 also provides some insight into the potential for phenotypic selection and selection at young ages in Alnus. Most of the trees selected for superior growth in the older Illinois and Ohio plantations gave rise to clones that ranked above average in growth after 2 years. The trend was more consistent for diameter than for height. The six clones that were selected under greenhouse conditions (Bajuk et al. 1978; Gordon and Wheeler 1978) have performed relatively well the first 2 years in the field. It will be important to

Table 6. Results of 2-year clonal study at Rhodes, Iowa. Clones are arranged in rank order by decreasing stem diameter.

------Clone------		Field	Diameter	----Height----		Number of Trees
Number	Source[1/]	Rating[2/]	(mm)	(cm)	(Rank)	Flowering/Surviving
42	IL	+	46.4	150.7	7	0/9
37	IL	+	36.7	179.5	1	0/6
14	OH	+	33.8	173.0	2	0/8
1-26	Ba		33.7	155.4	6	0/7
21	OH	-	33.4	159.8	4	0/5
1-23	Ba		31.8	145.0	10	0/8
40	IL	-	31.1	160.7	3	0/7
2-50	Ba		30.4	138.5	12	0/4
15	OH	+	26.1	113.4	20	0/8
41	IL	+	25.1	135.4	14	0/8
44	IL	+	24.8	156.5	5	0/2
33	IL	+	23.9	144.9	11	0/7
34	IL	-	23.2	134.0	15	4/7
3-21	Ea		23.0	148.5	8	0/2
32	OH	-	22.6	123.3	18	0/6
39	IL	-	22.2	135.8	13	4/8
5-50	Ba		21.8	131.0	16	0/1
30	OH	+	20.9	94.0	25	0/5
46	Rh		20.8	146.1	9	3/7
3-13	Ea		20.3	129.3	17	0/6
45	IL	-	19.4	120.6	19	3/5
19	OH	-	18.6	108.8	21	0/5
17	OH	-	17.7	84.5	27	0/4
25	OH	-	17.6	106.8	22	0/5
43	IL	-	16.8	90.4	26	0/5
20	OH	+	15.4	99.5	23	0/2
16	OH	-	14.9	97.3	24	0/4

1/ Location of ortet from which the clone was derived: IL = Illinois plantation; OH = Ohio provenance test; Ba = Bajuk greenhouse experiment; Rh = Rhodes, Iowa, provenance test.

2/ For field ratings a "+" indicates the ortet was one of the largest trees in the planting and a "-" indicates the ortet was one of the smallest trees in the planting.

continue monitoring field performance as a guide to the value of selection based on short-term physiological tests and controlled-environment growth.

The selection that was made from an exceptionally fast-starting border tree in the original Rhodes provenance trial was particularly interesting. Two-year height growth was quite good in the ramets just as it was in the ortet. After the selection was made, however, the ortet began flowering heavily, suffered from the Phomopsis-like canker, and lost its growth superiority. The ramets of this selection are now following a similar pattern (Table 6).

Overall clonal repeatability (broad sense heritability) at 2 years was 0.32 for height and 0.59 for diameter. Assuming there is sufficient similarity between this study and the way a mass selection/clonal propagation program based on the provenance tests would operate, an estimate of potential genetic gain in height can be calculated. The population values are taken from figure 1. If the best 5 percent of the phenotypes were taken this would represent a selection intensity (i) of 1.4. The standard deviation of the population at 3-years-of-age is 50.5 cm. Applying the estimate of 0.32 for clonal heritability, the potential genetic gain (ΔG) is:

$$\Delta G = ish^2_{BS} = (1.4)\ (50.5\ \text{cm})\ (0.32) = 22.6\ \text{cm}$$

Based on the overall population mean of 228 cm (figure 1), this would represent a 10 percent gain. To achieve greater genetic gain, it will be necessary to work with larger populations (so stronger selection intensities can be used), develop selection methods that are better than mass selection, and/or improve on cloning techniques so that nongenetic variation such as variable rooting does not lower the heritability of the desired traits. It does seem from this study that juvenile diameter growth is more strongly inherited and bears a better relationship with ortet performance than does juvenile height growth. In as much as each provenance is represented by a maximum of 32 trees at each test site (Maynard and Hall 1980), there is a need to establish much larger populations of the most promising provenances to support future selection and breeding efforts.

The age at which selections can first be made reliably is an important consideration for tree improvement. To study this question in A. glutinosa have analyzed two sets of available data: the annua measurements of individual tree heights in the current provenance tests and stem analysis measurements from trees in the earlier provenance test planted by Funk (1973) in Ohio. Table 7 gives the correlation matrix for age-to-age correlations in the 4-year-old provenance tests. As expected, first-year performance was not highly correlated with later performance, especially in the Wisconsin planting where southern provenances did grow well until after the first winter. The trend of improving correlations shown in the first 4 years (Table 7) does

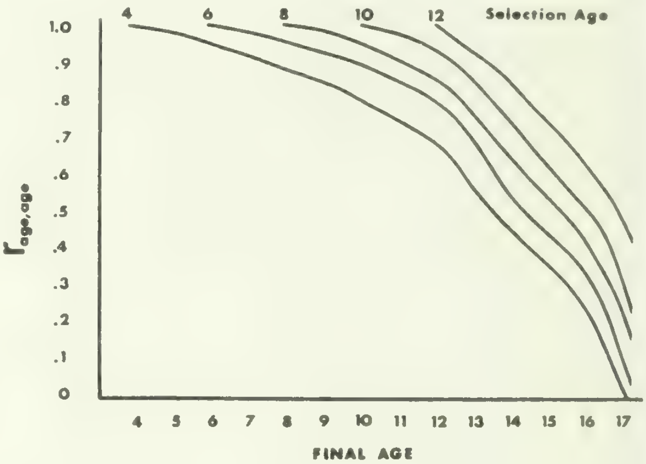

Figure 2. Correlations in total height between potential selection ages and harvest ages based on a 17-year-old provenance study in Ohio.

Table 7. Age-age correlations in total height of individual trees in the provenance tests. All correlations are based on over 1100 data points and are significant at the 0.0001 probability level.

	---------Rhodes, Iowa-------- Correlated with Height at:				--------Harshaw, Wisconsin---- Correlated with Height at:			
Height at	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4
Age 1	1.00	0.79	0.71	0.61	1.00	0.60	0.28	0.14
Age 2		1.00	0.81	0.74		1.00	0.73	0.52
Age 3			1.00	0.86			1.00	0.85
Age 4				1.00				1.00

:arry on in older trees as demonstrated in figure 2. However, beyond age 12, the age-to-age correlations for total height begin to decrease once again. If we use an r=0.7 (r^2=0.50) as our guiding limit that we wish to stay above (Steinhoff 1974), then selections for short-rotation intensive culture of A. glutinosa should be made at about 1/2 to 2/3 of the planned rotation age.

However, height, per se, is not our primary objective. Instead, we usually are most concerned with volume as an improvement goal. At nearly all selection ages, diameter is at least as good as, if not 0.1 to 0.15 correlation units better than, height as a predictor of volume production at future

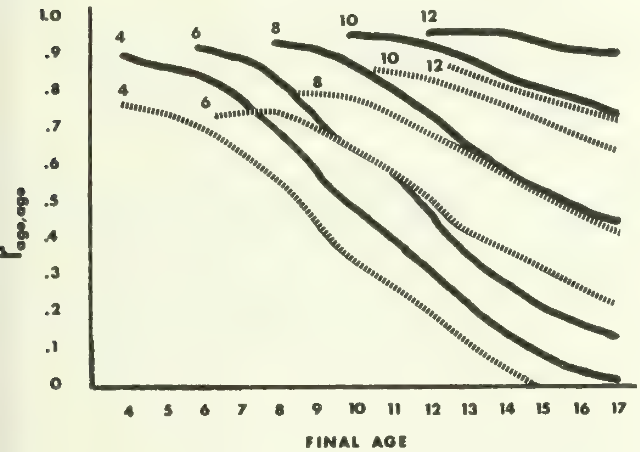

Figure 3. Correlations of height (IIIIIIIIIII) and diameter (▬▬▬▬) with volume production for various selection and harvest ages. Based on a 17-year-old provenance study in Ohio. Selection ages are indicated at the left end of each curve.

ages (figure 3). This adds to our previous argument for placing greater emphasis on selection based on diameter growth in tree improvement for intensive culture (see earlier discussion in this paper and Hall 1982). What remains is to find an efficient way of screening diameter differences in large test populations. In breeding for intensive culture, we probably also need to look at correlations with coppice production (Hall 1982), but no such studies have been initiated.

The final point on which we have been able to collect information to date is the relationship between vegetative growth and flowering. Previous work in A. glutinosa has indicated that the sudden increase in flower production that some trees undergo is responsible for their poor vegetative performance (Münch 1936; Verweij 1977; Funk 1979). Early flowering (short generation time) is desired in tree breeding programs, but could reduce our progress in improving woody biomass production (Hall and Miller 1980). Therefore, we have been following this relationship closely in the Rhodes plantation. A few trees in the Hungarian provenances (591 and 592) formed flower buds at the end of their second growing season. These same trees flowered again more heavily in each of the next two growing seasons, and additional individuals in a number of other provenances began to flower. As can be seen in Table 1, provenances 591 and 592 continue to be among the tallest trees in the study despite their flowering precocity. When the flowering and growth data are analyzed across the 16 provenances that had several trees flowering at age 4 (Table 8), the flowering trees average almost 2/3 m taller. Flowering trees also had slightly higher average growth in the latest growing season, but this effect was not statistically significant at the 5 percent probability level. In their studies of A. glutinosa Verweij (1977) and Funk (1979) also have observed that some of the fastest-growing trees began flowering first. Between the ages of 6 and 10, many of the precocious trees in their tests began to fall behind in vegetative growth. We will contine to study the relationship in our plantation in an attempt to refine our knowledge of what is occurring at older stages. However, the fact that a positive relationship between flowering and vegetative growth exists through at least the first 4 years is encouraging for the prospects of breeding Alnus for short-rotation biomass production.

Table 8. Flowering in relationship to total height and growth of 16 provenances at Rhodes, Iowa--year 4.

		Average in cm	
	Number	Total Height	1982 Growth
Flowering Trees	156	400	183
Non-Flowering Trees	310	334	174
Probability the means are same		0.0001	0.14

CONCLUSIONS

1. Cultural techniques for growing alders need attention while the genetic improvement effort continues. Planting stock alternatives, weed control during establishment, levels of acceptable stand competition, and coppicing techniques seem to be the most important voids in current understanding. An efficient method of cloning is needed so we can rapidly capitalize on superior individual selections.

2. Tremendous genetic diversity is present in the genus, but it needs much "repackaging" before we'll have exactly what we want.

   A. We will need to pay particular attention to stress tolerance and canker resistance.

B. Selection work will need to be done within each climatic zone, and probably by site class. For northern Wisconsin, emphasis should be placed on provenances from Poland and the Baltic States. For Iowa, and perhaps the central states in general, the emphasis should be on central European sources. For breeding work, selected parents from more northern and southern provenances should also be included in attempts to generate more optimal growing patterns over the season while retaining adequate winterhardiness. This also will help to maintain a broad genetic base in the breeding program.

C. Other speices of Alnus need to be evaluated. Alnus incana is likely to be of some use throughout the north central region. A. cordata may have value in central and southern states. A. accuminata from South America and several oriental species also deserve careful consideration. Inter- and intra-species breeding should proceed as rapidly as selected parents can be identified and flowering begins.

3. Although the present 4-year-old tests should not be used to project performance for more than an 8-year rotation, the data on climatic suitability should be reliable enough that we can begin to establish large populations of the most promising provenances. When these large populations reach the proper age, they can then be subjected to greater selection intensities to form the bases for long-range improvement efforts.

4. Diameter measurements need to receive greater emphasis in the selection of improved Alnus genotypes. Improvements in measurement techniques are needed before this will be practical for large scale programs.

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IRRIGATING FOREST PLANTATIONS

Edward A. Hansen[1]

Abstract.--Irrigating forest plantations cannot be justified economically on yield increases alone under present market conditions. Other factors such as bringing noncommerçial land into high production, insuring a constant wood supply, or providing a means to dispose of wastewater can add to the value of increasing yields and may make irrigation feasible in certain situations.

A major reason for irrigating forests is to increase yields. However, yield increases alone do not offset the added costs of irrigation (Rose et. al. 1981). Other associated benefits of irrigation are the reduced costs for land, harvesting, transportation, and land taxes that result from growing more fiber on less acreage (Mace and Gregersen 1975). These benefits bring irrigation closer to a break-even point. Additional potential benefits of irrigation that have been identified are to provide a means to dispose of wastes, (Hansen et. al. 1980), insurance against drought (Rose and Kallstrom 1976), and a secure source of raw material to a mill that would be costly to shut down (Rose et. al. 1981). But these values are difficult to assess and have not been incorporated into economic analyses of forest irrigation.

Even though forest irrigation has been done experimentally for more than 50 years, I am aware of only one area with a large acreage of irrigated plantations--340,000 acres in West Pakistan (Sheikh 1974). Consequently, the forestry literature contains little discussion of irrigation strategy from a management or economic viewpoint. However, the agricultural literature contains much parallel information. This paper examines some of the reasons behind the decisions for irrigated farming and applies that reasoning to the irrigation of short rotation intensive culture (SRIC) plantations. Benefits and possible negative aspects of irrigation are discussed with illustrations from data collected in irrigated hybrid poplar plantations in northern Wisconsin.

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For purposes of illustrating benefits on yield, an idealized view of the relation of tree yield to soil moisture is shown in Figure 1. Although the shape of the yield function over the range of soil moisture is not known, we do know that for a particular species on a specific site no tree growth will occur both at some very dry condition, and at the other extreme of some very wet condition. Somewhere in between these two extremes of soil moisture, tree growth reaches a maximum, the exact optimum soil moisture level varying with tree species. The right hand portion of the function illustrates excessive soil moisture and represents the condition where drainage would increase tree growth. The left hand portion of the function illustrates soil moisture deficiency and represents the condition where irrigation would increase tree growth. It is this drier portion of the soil moisture range that is of interest in this discussion.

Why Irrigate

Tree growth within the humid temperate region varies widely over a range of soil moisture conditions. Under these climatic conditions, irrigating dry sites may possibly produce growth rates similar to those naturally occurring on the very best sites--other factors being the same. Irrigation may be thought of as merely a substitute for insufficient soil moisture storage capacity. Depending upon the existing soil moisture holding capacity, sites may range from being incapable of supporting tree growth without irrigation to showing no additional growth response to irrigation. The value of irrigation for different severities of soil moisture deficit on agricultural soils has been discussed by Greenshields (1955), Tharp and Crickman (1955), and Marr (1967). I have summarized these irrigation benefits

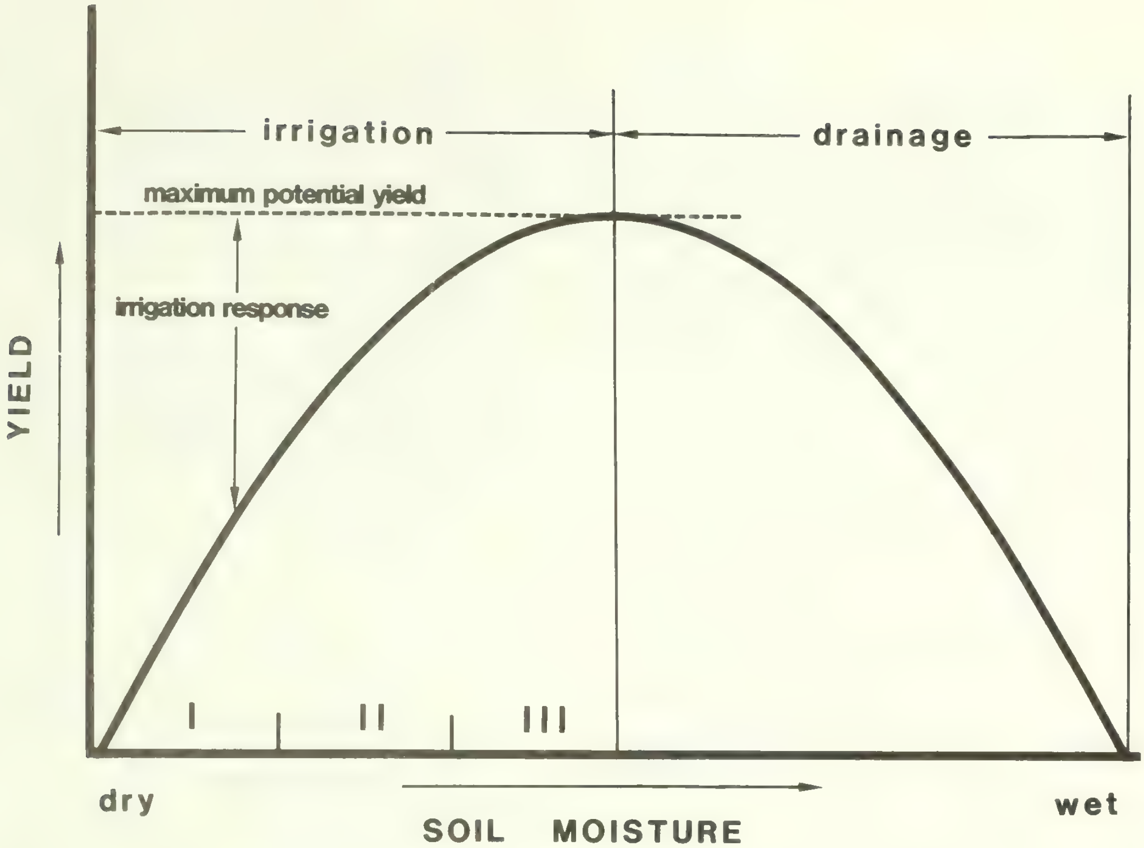

Figure 1.--Relation of tree yield (fiber or energy) to soil moisture. Irrigation (left half of the curve) can increase yield from the existing level, as illustrated by the curved line, up to the maximum potential yield. Drainage of the wet portion of the soil moisture spectrum can produce the same yield responses. Advantages of irrigation are classified into three categories:

Category I: create new commercial forest land.
Category II: increase probability (insurance) of producing a crop.
Category III: increase yield.

by classifying yield response into three arbitrary categories based on the value to a forest manager (fig. 1).

Category 1 represents very droughty soils where either there is no tree growth or the existing trees are noncommercial. Irrigating such land creates new commercial forest land. It is under these conditions that irrigation provides maximum gain in wood production.

Category 2 represents land capable of supporting forest without irrigation. However, chronic soil moisture deficits may substantially depress tree growth and infrequent droughts may result in substantial mortality or a crop failure. Irrigation under these conditions increases the probability of producing a commercial forest crop.

Category 3 represents land that is nearly certain of having sufficient soil moisture to produce a forest crop. Irrigation would slightly increase yields in most years.

The advantages of irrigation when viewed from this perspective are threefold. Increases in forest yield occur in all three categories, although the magnitude of increase differs greatly from one category to another. However, the important gains are that as sites become drier, irrigation has the added benefits of insuring that a crop will be obtained and creating new commercial forest land. The value of these latter two benefits would obviously differ by geographic area and by individual

wood users within an area.

Irrigation Effects on Yield

A review of more than 80 papers dealing with agronomic and horticultural crops concludes that yields are usually greatest with the wettest soil moisture regimes (Stanhill 1957). A review of forest irrigation indicates that irrigation usually increases tree growth (Hansen 1978). Even small decreases in soil moisture tension will increase the growth of forest trees (Zahner 1968). Irrigation research with hybrid poplars supports these conclusions. Preliminary results based on 3 years of irrigating hybrid poplar planted at 1 x 1 m spacing at Rhinelander, Wisconsin, show that irrigation consistently increased tree growth (fig. 2). In this study plots were irrigated whenever soil moisture reached the designated treatment level. For example, whenever the soil moisture reached -1.5 bar, the plots assigned that treatment were irrigated to field capacity. Consequently the wettest (-0.3 bar) treatment plots were irrigated 3 to 6 times during the summer whereas the drier (-1.5 bar) treatment plots were only irrigated 0 to 4 times. The "no-irrigation" plots served as a control.

The wettest irrigation treatment of -0.3 bar produced yields 76 and 44 percent greater than the unirrigated controls at the end of the second and third growing seasons, respectively (Table 1). The effect of irrigation on increased yield in weight was the same both years (about 1.5 t/ha/yr).

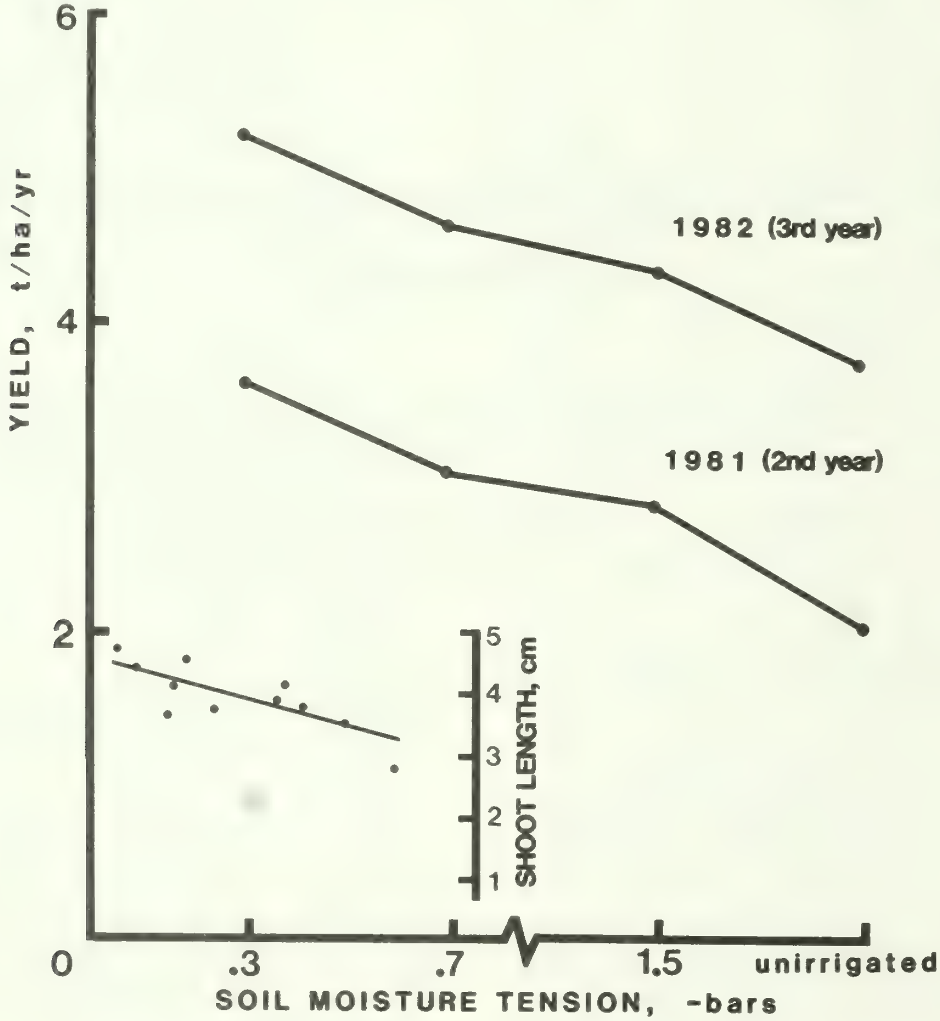

Figure 2.--Effects of soil moisture tension (irrigation) on 10 day shoot length and on 2nd and 3rd year yields.

Table 1.--Effect of irrigation on yield.

Year	Treatment -0.3 bar	Treatment not irrigated	yield increase	
	----------- t/ha/yr	-----------		%
2	3.5	2.0	1.5	76
3	5.3	3.7	1.6	44

What Soil Moisture Tension is Best?

The same irrigation study showed that tree growth during a 3-year period was satisfactory under all irrigation treatment regimes including no irrigation, but tree growth was greatest with the highest irrigation treatment (fig. 2). Although the highest level of irrigation increased total aboveground yields by 44 to 76 percent, irrigation is not essential for growing trees on that site and so far has not been needed as insurance against infrequent drought. Consequently, this site would probably fall within Category 3 (or possibly 2) (fig. 1).

We investigated the effects of soil moisture tension from -0.6 bars to -0.05 bars on early growth of hybrid Populus hardwood cuttings in a growth room (Hansen and Phipps, in press). The soil moisture treatments were obtained by using boxes, each filled with soil at a different soil moisture tension. Unrooted cuttings were then placed in the boxes and we observed their early growth.

The results indicate that bud opening and shoot growth begins sooner as soil moisture tension decreases to at least-0.05 bar (fig. 2). The results of this growth room study together with the results of the field study indicate that the conclusions of Stanhill (1957) and Zahner (1968) also apply to hybrid poplar, i.e., yields are greatest with the wetter soil moisture regimes.

When to Irrigate?

It is sometimes argued that irrigation is most important during plantation establishment, because at this time drought might result in total failure of the plantation (Rose et. al. 1981). In contrast, absence of irrigation in older plantations presumably might only reduce growth but not affect survival, assuming that the plantation is established on a site of at least moderate quality. But is this the case? And how frequently might such conditions occur?

In 1981 we studied growing season soil moisture conditions under a newly established plantation and also under a 2-year-old plantation both with and without irrigation (fig. 3). Soil moisture stress reached higher tensions under the 2-year-old plantation. Irrigation did not produce significant differences in tree height growth in the new plantation but did produce significant biomass differences with the 2-year-old trees.

Rain during July and August of 1981 was well below average:

		July	August
Average precipitation	(mm)	3.53	4.27
1981 precipitation	(mm)	1.18	0.82

Despite this exceptionally low rainfall, the newly planted unirrigated plots survived and grew satisfactorily. Therefore, it appears that severe mid-to late-summer droughts do not prevent establishment of hybrid poplar plantations in northern Wisconsin.

These plots had good weed control. Soil moisture tensions in weedy plantations would be more severe. Also, drought in May or June might have a negative impact on survival. Both these factors might increase the need for irrigation during plantation establishment. On the other hand, soil moisture in northern Wisconsin is at field capacity in early spring, soil moisture can be conserved by good weed control, and cuttings can be soaked prior to planting to compensate for "dry" (-0.6 bar) soil moisture conditions (Hansen and Phipps, in press). These latter three factors decrease the possibility of encountering severe moisture problems in early spring when establishing plantations.

Although irrigation may in some cases be essential to establish a plantation, it appears that such instances are infrequent in northern Wisconsin.

Negative Effects of Irrigation

It is sometimes argued that irrigation will promote leaf diseases because of increased duration of leaf wetness (Rose et. al. 1981, Schipper 1976, Uriu and Magness 1967). However, the total duration of leaf wetness during a growing season is affected only to a very minor extent by irrigation. Typically, we irrigated on only 1 or 2 days per month whereas it rained on 8 to 15 days per month (table 2). Even in a very dry month rainy days outnumbered irrigation days by 2 to 1

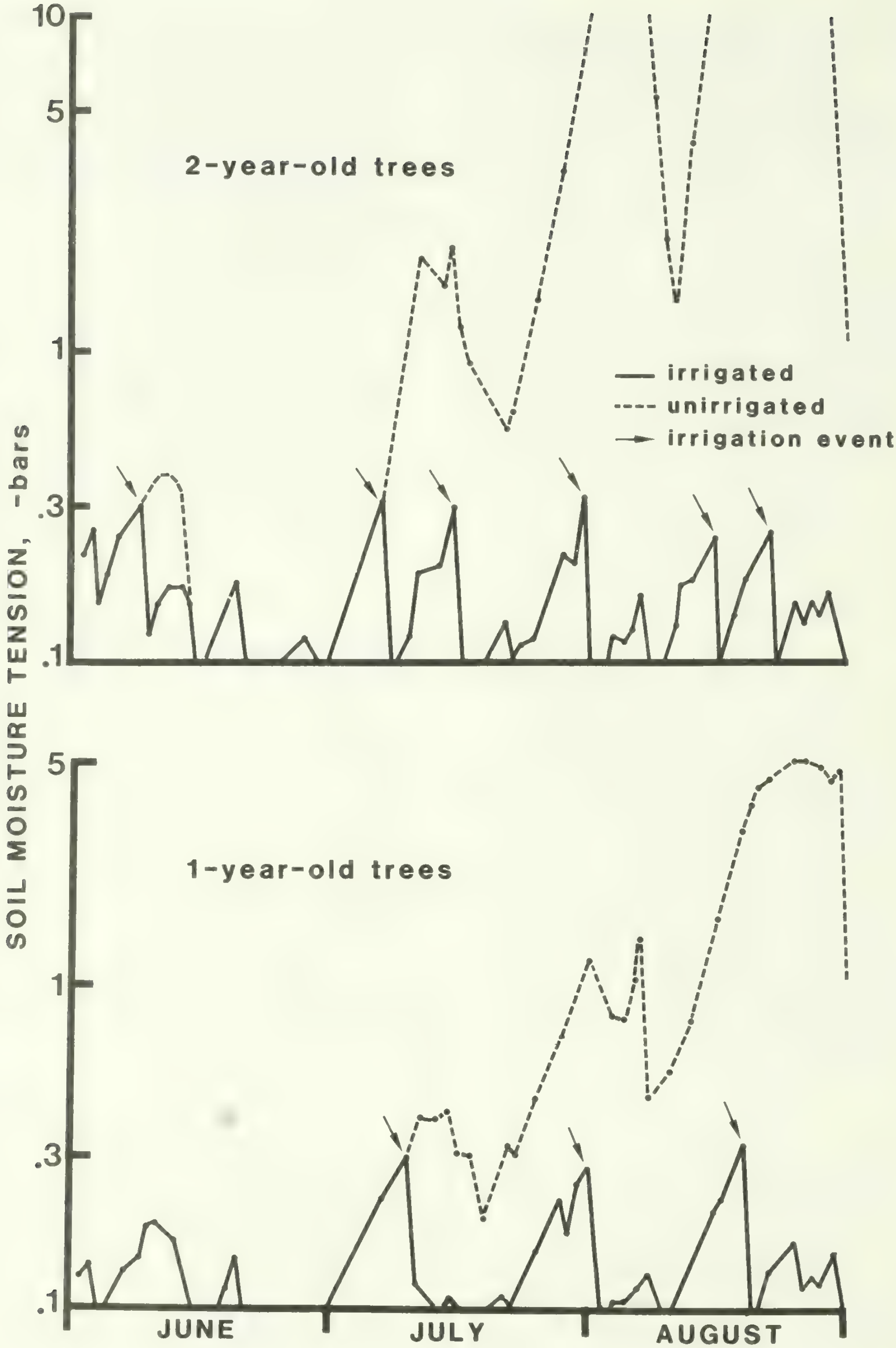

Figure 3.--Soil moisture tension trends under intensively cultured plantations with and without irrigation during the 1st and 2nd growing seasons. Irrigation was done when tensions reached -0.3 bar.

Table 2.--Comparison of the number of days per month with precipitation (P), or irrigation when soil moisture tension reached -0.3 bar ($I_{.3}$) or -0.7 bar ($I_{.7}$) during the first three growing seasons. Irrigation lasted less than 1 hour for a particular tree; precipitation typically lasted from one to several hours. Frequently it rained several times in 1 day, and occasionally it rained an entire day.

Month	1980			1981			1982		
	P	$I_{.3}$	$I_{.7}$	P	$I_{.3}$	$I_{.7}$	P	$I_{.3}$	$I_{.7}$
	days								
May	5	0	0	7	0	0	12	0	0
Jun	11	1	0	15	1	0	6	2	2
Jul	13	1	0	6	3	1	12	2	1
Aug	14	1	0	8	2	1	8	2	1
Total	43	3	0	36	6	2	38	6	4

when compared to the wettest irrigation regime (see July 1981 when only 1/3 of the normal monthly rain occurred). Even then only one irrigation was applied to the -0.7 bar treatment, which is a common soil moisture tension level in agronomic practice at which to irrigate. A maximum of 6 irrigation days in any one season compares with 36 to 42 rainy days in the same period.

An additional factor is that irrigation of a particular tree lasts less than an hour under our travelling gun system. In contrast, rain may last anywhere from a fraction of an hour to a day. Also, weather conditions associated with rainfall often minimize evaporation so that leaf surfaces remain wet for a long time. In contrast, irrigation is usually done when weather conditions are dry and leaves dry rapidly, thus minimizing duration of leaf wetness. The greatest number of irrigation days occur in dry years. Wet years may need no supplemental irrigation. Therefore, irrigation tends to bring leaf environmental conditions in dry years slightly closer to that experienced naturally in wet years.

Another factor to consider in addition to rain and irrigation is the occurrence of dew. Although we have no direct measurements of dew formation, relative humidity data can be used as an index of the presence of dew. During the June - August growing season, relative humidity reached 100 percent almost every night each of the 3 years and remained at 100 percent for generally 6 to 12 hours. Although relative humidity of 100 percent is not conclusive proof that dew occurred, it is supported by field observations that dew was present almost every night during the summer growing season and normally persisted until mid-morning of each day.

It appears that irrigation is a minor factor in increasing the frequency of leaf wetness during the growing season. It also seems unlikely that the duration of wetness from irrigation will exceed that of either rain or dew. Therefore, irrigation is probably not an important factor in the spread of tree diseases.

Discussion

Analyses conclude that irrigation is not economical for hybrid poplar SRIC plantations yielding 15 t/ha/yr (Rose et. al. 1981). And the yield used in these analyses has been reached only in two of our small research plots (Ek and Dawson 1976). Therefore, this yield could be considered a record. Boyer (1982) shows that average yields for grain crops are only 1/7 that of record yields. Crops such as potatoes and sugar beets with marketable vegetative structures have average yields about 1/3 that of the record yields. Therefore, it seems likely that the average yields of hybrid poplar will be much less than (perhaps half?) the 15 t/ha/yr achieved in our small research plots. Although further research in intensive culture will likely increase yields, it will probably be a long time before the present average yields increase to the levels of the record yields. Therefore, it is unlikely that irrigation will soon become economical when justified on average yields that may be achieved in the foreseeable future.

It does not seem likely that irrigation will be justified based on its need for establishing plantations. Our data show little need for irrigation during the year of plantation establishment, even during an exceptionally dry summer. Also, the establishment period is one of the few times when alternatives to irrigation are available for managing

soil moisture. Good weed control can substitute for irrigation and at a fraction of the cost. For example, post-planting weed control costs from \$3.00 to \$13.00/acre compared with irrigation costs of \$100/acre for annual operation plus \$43.00/acre fixed cost for equipment (Rose et. al. 1981).

Irrigation probably has little impact on the duration of leaf wetness during the growing season. Therefore, it seems likely that irrigation is not an important factor in the spread of tree diseases.

Irrigation has not been able to be economically justified based on its influence on woody biomass yields in the past, and it seems that justification based on further increases in yields will be difficult in the foreseeable future. Consequently, if irrigation is "to pay", it must do so on the basis of other benefits in addition to the documented favorable impact on yields. Additional justification for irrigation must rely to a large extent upon 1) the value of bringing new (previously unproductive) land into the highest levels of production and being able to locate such land near a mill, and 2) the insurance value of greatly reducing risks of growth or mortality losses directly from drought or from secondary attacks by insects and diseases thus assuring a stable fiber supply. Also to be considered is the value of using the land for wastewater disposal via irrigation. These factors must be considered in any determination of whether or not to irrigate, even though their consideration may be highly subjective. Although analyses have shown irrigation of SRIC plantations with a travelling gun system to be uneconomical when based on yields alone, other factors may make irrigation attractive to some large forest land holders.

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EFFECT OF HARVESTING SEASON ON HYBRID POPLAR COPPICING

by

Terry F. Strong and Jerry Zavitkovski

Abstract.--A study was begun in 1980 in a 4-year-old planting of P. nigra var. betulifolia x P. trichocarpa to identify the effects of harvesting season on coppice production. Parts of the plantation were harvested monthly from October 1980 to September 1981. The trees were cut leaving 10 and 30 cm (4 and 12 in) stumps. Coppice measurements were taken 1 year after harvest. Harvesting during the leafless season (October to mid May) positively affected (a) stump survival, (b) height and d.b.h. growth of dominant sprouts, and (c) number of live sprouts/stump taller than 1.37m. Harvesting during the growing season discouraged coppicing. Stump height had no effect on stump survival or growth of dominant sprouts. However, stump height positively affected number of sprouts/stump. Therefore, to concentrate growth on a few sprouts, the stumps should be kept short. The 10 cm (4 in) stumps proved adequate.

In their review of factors influencing coppicing, Blake and Raitanen (1981) state that where species exhibit a seasonal variation in coppicing, sprouting is usually maximal when trees are cut in winter and minimal when they are cut in mid-summer. With some caution, the same generalization could be made about hybrid poplar coppicing. Good coppicing and coppice growth followed dormant season harvest of eastern cottonwood (DeBell and Alford 1972), various P. x euramericana clones (Lee and McNabb 1979), and P. 'Tristis #1' (Strong and Zavitkovski 1982). Poor coppicing followed growing season harvest in those studies. However, Anderson's (1979 b) studies, although consistent with the above results for P. x euramericana (clone I-45/51), showed that some aspen-type clones had good tolerance to growing season (July or August) harvesting. Obviously, poplar clones may respond differently to the season of harvest and each clone should be tested separately to determine its optimum harvesting time. Such knowledge may substantially increase the yield of the subsequent poplar coppice.

The objective of this study was to assess the effect of harvesting time on coppicing of clone NE-299 (NC-5331), a hybrid between P. nigra var. betulifolia x P. trichocarpa. The specific objectives were to establish between season of harvesting and (a) stump survival, (b) number of shoots per stump, and (c) height and d.b.h. growth of the dominant sprouts 1 year after the harvest.

MATERIALS AND METHODS

The study was conducted in a 4-year-old 0.25 ha plantation of NE-299 (NC-5331) established at 1.2 x 1.2 m (4 x 4 ft) spacing at the Harshaw Forestry Research Farm near Rhinelander, Wisconsin. The plantation was divided into 2 replications. Within each replication we staked out 12 plots, each with 55 trees (5 rows with 11 trees each). The plot size was 6 x 13 1/2 m (20 x 44 ft).

The sequence of cutting was randomized within each replication. One plot in each replication was cut in the middle of every month from October 1980 to September 1981. Three rows were harvested leaving a 30 cm (1 ft) stump and 2 rows were harvested leaving a 10cm (4 in) stump. At the time of harvest, we recorded the diameter of the stump at the cut surface.

Coppice measurements were taken 1 year after harvest or, for trees harvested during the dormant season, any time during the following dormant season. The following data were recorded:

(a) number of living stumps,

(b) height of the dominant sprout on each stump,

(c) d.b.h. of the dominant sprout on each stump, and

(d) number of live sprouts/stump taller than 1.37 m.

We analyzed the data by means of analysis of riance and regression analysis, and we tested e significance of specific comparisons by a " test with a confidence level of 95%.

RESULTS AND DISCUSSION

Physiologically, October and May are not rmant season months. However, we found no gnificant difference between harvest months thin the October to May period in stump rvival, number of sprouts/stump, and height d d.b.h. growth. Therefore, we pooled the ta for that period (called dormant season in is paper). Although stump survival following e September harvest did not differ from that dormant season harvesting, number of sprouts, ight, and d.b.h. were substantially smaller. owing season harvesting, June through August, s the least productive and had the lowest ump survival.

Stump Survival

The average stump survival was 92% for the ptember through May harvests (table 1). It s 65% for the June harvest and less than 10% r the July and August harvests. Stump survival r the growing season harvests was lower than e 62% found in the previous study with P. ristis #1' (Strong and Zavitkovski 1982).

harvested in July, August, and September. Whereas the July and August harvests were followed by low to intermediate stump survival (except for *P. canescens* cl. 'Ingolstadt' whose stump survival was 90 to 100% in all 3 months of testing), stump survival following the September harvest was 100% in three clones and 80 to 30%, respectively, for the other two clones. Such results are more typical of a dormant season month. However, based on height and d.b.h. growth reached in our study, September could be classified as a growing season month. Perhaps more appropriately, September is a transition month that may have dormant or growing season characteristics depending on the weather preceding the harvest.

Height of Dominant Sprouts

The average height of the dominant sprouts ranged from 0.9 for the June-August harvests to 2.3 m for the dormant season harvests (table 1). In a previous study with P. 'Tristis #1' (Strong and Zavitkovski 1982), the respective heights were 0.9 and 1.6 m. The ratio between the dormant season and growing season heights was 2.6 in the present study and 1.8 in the previous study. This compares with a ratio of 1.7 obtained by DeBell and Alford (1972) in a study with *P. deltoides* in Mississippi.

First year average height of the dominant sprouts developing after the dormant season harvesting, 2.3 m, was similar to heights reported by Anderson (1979 a) for clone 1-45/51 in Ontario

Table 1.--Effect of harvesting season on stump survival and coppice development of poplar hybrid NE-299 (NC-5331)

Month	Stump survival			Growth of dominant sprouts: Height			d.b.h.			Number of sprouts[1/]		
	Mean	SD	N[2/]	Mean	SD	N	Mean	SD	N	Mean	SD	N
	(%)			(m)			(cm)					
October to May	92^{a}	8	32	2.3	0.4	294	0.9	0.2	293	7.5	3.7	293
September	93^{a}	5	4	1.5	0.3	34	0.5	0.1	25	3.4	2.3	25
June	65^{b}	10	4	0.9	0.3	26	0.6	-	1	2.0	-	1
July	9^{c}	11	4	0.7	0.1	3	-	-	-	-	-	-
August	5^{c}	10	4	1.1	0.2	2	-	-	-	-	-	-

1/ Sprouts taller than breast height (1.37 m).
2/ Number of observations

It is difficult to classify September either as growing season or dormant season month. Stump rvival following September harvesting was typical that achieved in dormant season harvesting. A milar conclusion could be drawn from Anderson's 979 b) studies with five different poplar clones (ranging from 1.96 to 2.04m), Crist et al (appears elsewhere in this publication) for P. 'Tristis #1' in Rhinelander (ranging from 1.84 to 2.19m), and Zavitkovski (1982) for various northeastern (2.46m) and *P.* x *euramericana* clones (2.27m).

Diameter of Dominant Sprouts

The average d.b.h. of dominant sprouts of individuals harvested during the dormant season was 0.9 cm and that resulting from the September harvest 0.5 cm (table 1). Only one dominant sprout reached breast height (1.37 m) following the growing season (June to August) harvest. In our previous study with P. 'Tristis #1' (Strong and Zavitkovski 1982), the average dominant sprout d.b.h. following the dormant season harvest was 0.93 cm. Anderson (1979 a) reported average d.b.h.'s of winter harvested 1-45/51 ranging from 0.94 to 0.97 cm. Although the average d.b.h. of winter-harvested eastern cottonwood (DeBell and Alford 1972) was substantially greater than achieved in our study, the same principle of less growth after the growing season harvest applied.

Season of Harvest and Number of Sprouts/Stump

The average number of sprouts taller than 1.37 m (breast height) was 7.5 for stumps of trees harvested during the dormant season and 3.4 for those harvested in September (table 1). Only one sprout taller than 1.37 m was produced following the June to August harvest. In the previous stud with P. 'Tristis #1' (Strong and Zavitkovski 1982 an average of 2.5 sprouts/stump taller than breas height developed after the dormant season harvest and winter harvested eastern cottonwood in Missis- sippi (DeBell and Alford 1972) produced an averag of 5.3 sprouts/stump taller than breast height.

Stump Size and Coppicing

Stump height had little effect on stump surviva or height of dominant sprout. Dominant sprouts originating from 30-cm stumps were only slightly larger in diameter than those origninating from 10-cm stumps (table 2). However, stump height ha a substantial effect on number of sprouts/stump. The 30-cm stumps had 8.8 sprouts/stump and the 10-cm stumps 6.2 sprouts. Similar findings were reported by Crist et al. (appears elsewhere in thi publication) for P. 'Tristis #1' and Belander (19 for sycamore. Both noted that several years afte harvest, number of sprouts/stump tended to equali

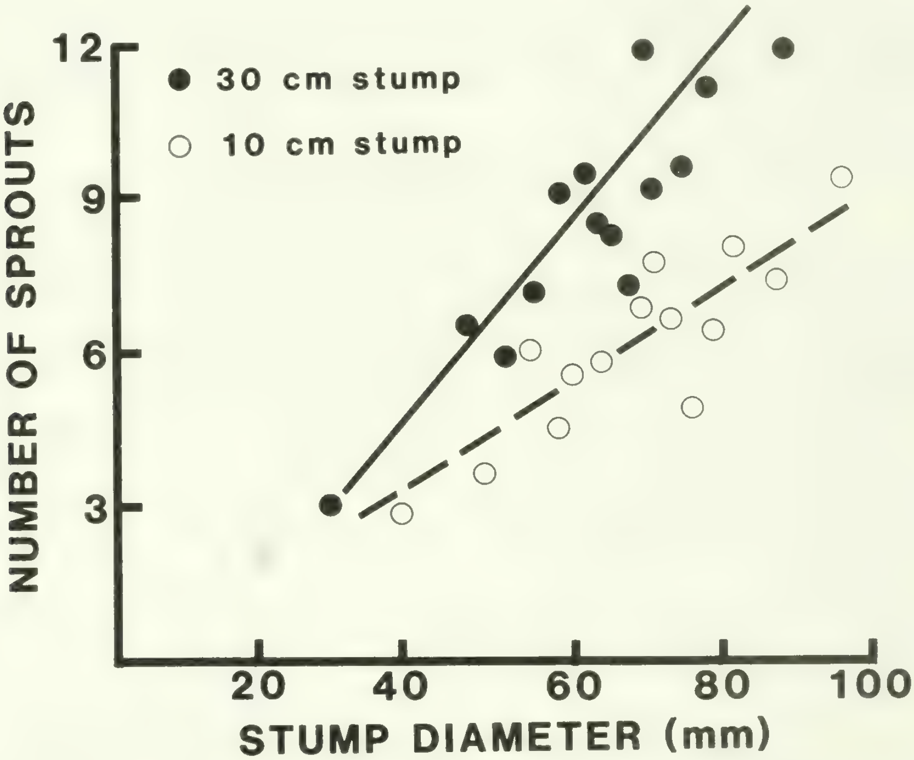

Figure 1.--Relation Between Stump Diameter and Number of Sprouts/Stump for 10-and 30-cm Stumps

ue to sprout mortality. In a similar study with astern cottonwood, DeBell and Alford (1972) found o significant difference due to stump height in umber of sprouts/stump or diameter and height rowth of sprouts.

Table 2.--Effect of stump height on coppice development

Stump Height	Coppice Development		
	Height	d.b.h.	Sprouts/Stump
(cm)	(m)	(cm)	(Number)
30	2.19	0.98	8.8
10	2.11	0.89	0.2
F-ratio	1.73	10.34*	40.97*

*Significant at the 95% confidence level

Number of sprouts/stump was also positively elated to stump diameter at the cut surface Fig. 1). Belanger (1979) reported similar re- tions for sycamore and we noted a similar trend n our studies with P. 'Tristis #1' (Strong and avitkovski 1982).

CONCLUSIONS

1. Dormant season harvest (October to May) of ybrid poplar NE-299 (NC-5331) positively affected) stump survival, (b) height and d.b.h. of dom- ant sprouts, and (c) number of sprouts/stump.

2. Dormant season harvesting is strongly re- mmended to maximize coppice production in the ke States.

3. July-August is the best harvesting time to scourage sprouting.

4. Stump height positively affected number of routs/stump.

Therefore, to concentrate growth on a few routs, the stumps should be kept short. Here, umps 10 cm (4 in) in height proved adequate. To courage number of sprouts for cutting production, t higher (30 cm).

ACKNOWLEDGMENT

We thank Drs. T. J. Blake and Neil Nelson for eir review of this manuscript.

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EFFECT OF SEVERING METHOD AND STUMP HEIGHT ON COPPICE GROWTH

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Abstract.--In this study we evaluated the effect of stem severing method and stump height on coppice growth in a short-rotation intensively cultured Populus plantation 1, 2, and 3 years after cutting. Initially, stumps 46 cm high had smaller and significantly more sprouts than either 8 or 15 cm high stumps. However, the dominant sprouts were not affected by the stump height. After subsequent growing seasons, the dominant sprouts were the only ones to survive, and no effect of stump height was present. Severing method--shearing or chain sawing--did not affect coppicing as long as the stumps were not excessively damaged during the original harvest.

Short-rotation intensive culture (SRIC) of trees is a promising way to increase wood biomass productivity (U.S. Department of Agriculture, Forest Service 1980). The Populus genus has been shown to be extremely productive under SRIC and to be good raw material for reconstituted forest products.

Either rooted or unrooted poplar cuttings are usually planted for the first rotation of a SRIC plantation. Subsequent rotations result from coppice sprouts regenerating from the stumps that remain after the first harvest and from short sprout stubs after coppice rotations (International Energy Agency 1981). However, little information is available on the effect of stem severing method and stump height on subsequent coppice growth.

The objectives of this study were to evaluate the effect of two methods of severing trees--sawing and shearing--and three residual stump heights--8, 15, and 46 cm (3, 6, and 18 inches)--on the number of coppice sprouts per stump, average sprout height and diameter, and dominant sprout height and diameter.

MATERIAL AND METHODS

Populus 'Tristis #1' trees (P. tristis x P. balsamifera) were grown at the Hugo Sauer Nursery near Rhinelander, Wisconsin. The plot was cultivated, fertilized, and irrigated to maintain optimum growing conditions for 6 years at a 0.6- by 0.6-m (2- by 2-ft) spacing; it had 36 rows of 12 trees each, for a total of 432 trees. However, at the harvest the plot contained only 315 trees because some trees had died and some had been removed for biomass determinations. At harvest, nonborder trees averaged 7.2 m (23.6 ft) in height and 5.6 cm (2.2 in) in diameter measured at 0.3 m (1 ft) above ground.

The trees were harvested during the dormant season (February 24, 1979) by either sawing or shearing. The sawing was done with a chain saw, and the shearing was done with a thin-bladed shear. The stems were severed at three heights, 8, 15, and 46 cm. These stump heights were chosen to include a practical range for mechanized harvesting equipment (8 and 15 cm) and one that might be necessary under heavy snow conditions (46 cm).

The six treatment combinations were used in a factorial experiment. We used a randomized complete block design with two replications. Standard analysis of variance techniques were used to evaluate the effect of stump height, severing method, and replication on the measured output variables. The total subplot area of each treatment was harvested by the prescribed method, and four adjacent nonborder stumps within each treatment were designated for subsequent coppice measurement.

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After each of the first three growing seasons, all sprouts longer than 0.3 m (1 ft) were measured on each of 48 stumps (4 stumps/treatment x 6 treatments x 2 replications). The measurements were: total number of sprouts/stump, height (length) of each sprout from point of attachment to its tip, and diameter of each sprout measured at 0.3 m (1 ft) from point of attachment.

RESULTS AND DISCUSSION

Mortality

The method of severing the stems initially affected coppice sprout mortality. Five of the 48 stumps on which coppice growth was measured (24 sawn and 24 sheared) died before the first growing season. All of these dead stumps had been sheared. Although the stumps could have been killed by the shearing action itself, death was probably caused by physical damage inflicted during positioning of the shear. The shear used in this study was for larger trees and was so large that when one stump was being severed, its neighbors were occasionally damaged. The five stumps that died were also much smaller than average (2.4- to 4.7-cm stump diameters), which may have made them more susceptible to damage by the shear.

Two more stumps died, one sawn and one sheared, after the second growing season. These two stumps were also small (1.8 and 2.8 cm in diameter), and their death was probably due to increasing competition and not mechanical damage. In our opinion, the damage to residual stumps could be greatly reduced or eliminated by designing special harvesters for small trees grown in closely spaced plantations. (Mattson et al. in this proceedings). Recent data indicate that wider spacings may be more economically feasible for SRIC systems (Rose and DeBell 1978). Wider spacings would also reduce damage by allowing more area for harvesters to operate. A rectangular spacing with wider between-row spacing and closer within-row spacing could also be used to facilitate harvesting.

Number of Sprouts per Stump

After the first two growing seasons, residual stump height affected the number of coppice sprouts per stump (table 1). The shortest stumps (8 and 15 cm) had significantly fewer sprouts than the tallest stumps (46 cm). However, sprout numbers were not significantly different between the 8 and 15 cm stumps. These results were expected because shorter stumps have less surface area for originating sprouts.

By the third growing season, the number of sprouts per stump was significantly less. The average number of sprouts had decreased from 13 to 3 and no effect of stump height remained (fig. 1). This decrease was expected because competition between the sprouts caused the weaker sprouts to die back. Similar to the results reported by DeBell and Alford (1972), the point of attachment of the surviving sprouts after three growing seasons was always on the top portion of the residual stump (fig. 2). This indicates that no advantage is gained by leaving higher stumps. In fact, the higher stumps could increase the possibility of stump decay in later years. Severing method did not significantly affect the number of sprouts per stump.

Average Sprout Height and Diameter

Residual stump height also initially affected both average coppice sprout height and diameter (fig. 3). For the first 2 years the 8- and 15-cm stumps had significantly taller sprouts of larger diameter than the 46 cm stumps. But average sprout height and diameter between the 8- and 15-cm stumps were not signifiantly different.

These results may have a logical physiological explanation. Assuming each residual root system has equal or similar amounts of stored photosynthate (or energy), then the sprouts on the shorter stumps may receive more energy for early growth because of the fewer sprouts on the shorter stumps. Also, because the stumps themselves utilize part of the stored energy for respiration and growth, the taller stumps would require more energy than the shorter stumps, leaving less energy available for coppice growth on the taller stumps. Severing method did not significantly affect average sprout height or diameter.

Height and Diameter Of Tallest Sprouts

Neither residual stump height nor severing method significantly affected the height of the tallest sprout on each stump (fig. 4). These results appear to conflict with the previous explanation for the differences observed in average sprout height and diameter. However, when the sprouts develop their first leaves, they cease to be sinks for stored photosynthate from the root system and begin to be sources of photosynthate. Because the tallest sprouts are dominant, they produce more photosynthate than other sprouts on the same stump and photosynthate can be used to accelerate height growth. The original effect of stump height becomes masked by the rapid height growth of these dominant sprouts.

Table 1.--Effects of stump height and severing method on growth of SRIC Populus 'Tristis #1'coppice.

Severing Method: and stump height	Year	Number of stumps	Average of all sprouts: Number	Height	Diameter	Average of tallest sprouts: Height	Diameter
				cm	cm	cm	cm
Sawn:							
8 cm	1	8	11.1 (4.8)[1]	119 (20.4)	0.88 (.20)	190 (36.9)	1.52 (.34)
	2	8	8.8 (3.4)	201 (48.7)	1.22 (.32)	390 (118.0)	2.40 (.84)
	3	7	3.9 (2.0)	371 (83.4)	2.24 (.62)	483 (46.9)	3.07 (.67)
15 cm	1	8	9.9 (3.6)	125 (15.8)	.92 (.13)	219 (20.9)	1.70 (.19)
	2	8	7.5 (3.4)	213 (39.1)	1.33 (.27)	446 (57.6)	2.90 (.64)
	3	8	2.2 (.89)	424 (82.7)	2.78 (.65)	496 (81.1)	3.43 (.99)
46 cm	1	8	13.6 (2.8)	116 (15.0)	.76 (.14)	208 (17.8)	1.50 (.21)
	2	8	11.0 (3.9)	182 (35.2)	1.06 (.22)	427 (36.4)	2.80 (.56)
	3	8	3.5 (.93)	342 (43.1)	2.06 (.36)	488 (50.2)	3.42 (.92)
Sheared:							
8 cm	1	6	8.3 (3.6)	118 (18.7)	1.0 (.15)	196 (27.2)	1.84 (.23)
	2	6	6.0 (3.3)	239 (34.8)	1.66 (.26)	446 (63.4)	3.40 (.50)
	3	6	3.0 (1.8)	387 (54.6)	2.82 (.33)	518 (75.3)	4.23 (.73)
15 cm	1	5	14.0 (8.5)	120 (15.4)	.89 (.19)	207 (44.0)	1.63 (.20)
	2	5	12.0 (6.7)	202 (51.7)	1.26 (.29)	417 (50.7)	2.80 (.84)
	3	5	4.2 (2.2)	352 (65.4)	2.27 (.61)	470 (74.2)	3.48 (1.2)
46 cm	1	8	20.1 (9.1)	98 (15.1)	.68 (.10)	184 (34.0)	1.42 (.32)
	2	8	14.9 (7.2)	160 (26.6)	.95 (.17)	402 (107.0)	2.70 (.87)
	3	7	4.0 (1.0)	361 (30.0)	2.33 (.31)	499 (44.0)	3.90 (.75)

[1]Entries are average values for the given number of stumps (observations). Number in parentheses is the standard deviation.

After three growing seasons, the dominant sprouts have clearly emerged. Of the 41 living stumps, 37 had from 1 to 3 sprouts that were taller than 400 cm. These dominant sprouts were similar in height and diameter. The taller sprouts were also usually the larger in diameter and vice versa. Of the 41 tallest sprouts, 37 were also the largest in diameter.

CONCLUSIONS AND RECOMMENDATIONS

Stump height initially affected the number of coppice sprouts per stump and average sprout height and diameter. However, after only three growing seasons, the smaller, weaker sprouts had already become victims of competition and from one to three dominant sprouts had emerged. We expect these dominant sprouts to survive despite the increasing competition. Each stump, regardless of its height or how it was severed, would have from one to three sprouts containing nearly all of the areal portions of biomass in the plot. We recommend not leaving high stumps unless deep snow conditions during harvest require it because they lose more biomass and have a higher possibility of stump decay than short stumps. Severing method did not affect the sprouting of the stumps unless they were severely damaged during harvesting.

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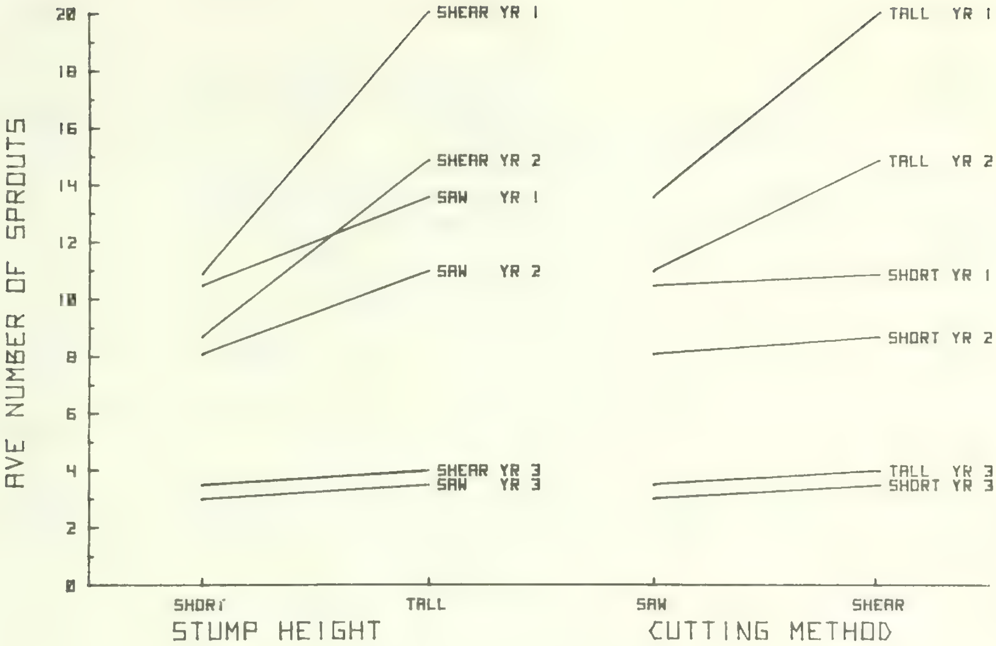

Figure 1.--Average number of spouts per stump for Populus 'Tristis #1' coppice by cutting method and stump height 1, 2, and 3 years after harvest.

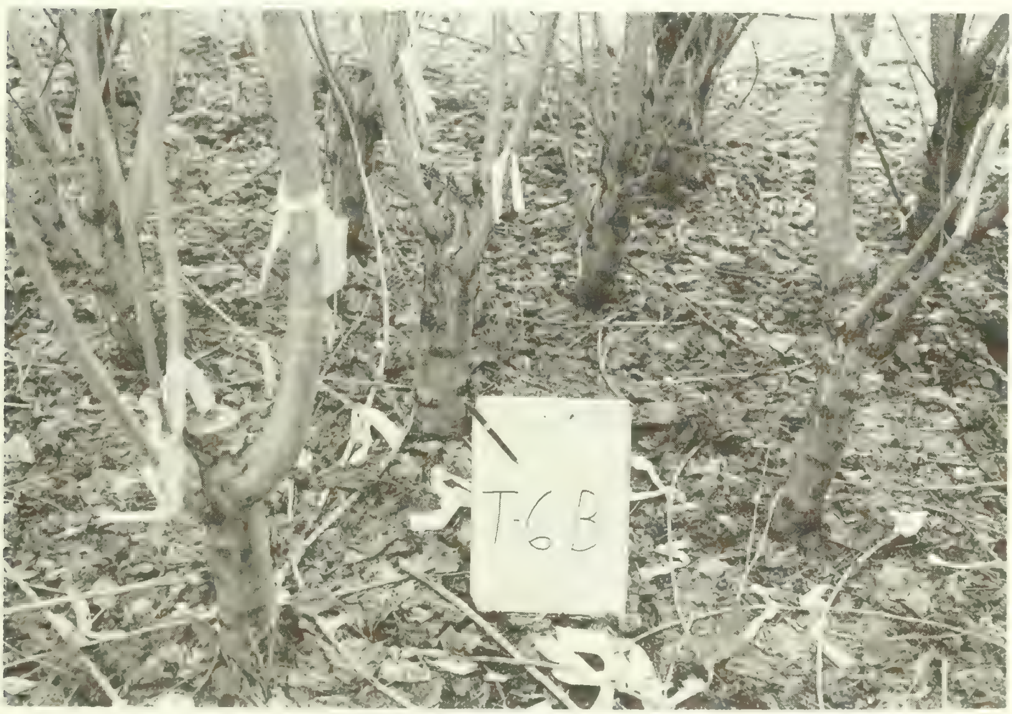

Figure 2.--Typical sprouting on 46 cm high Populus 'Tristis #1' stumps after three growing seasons.

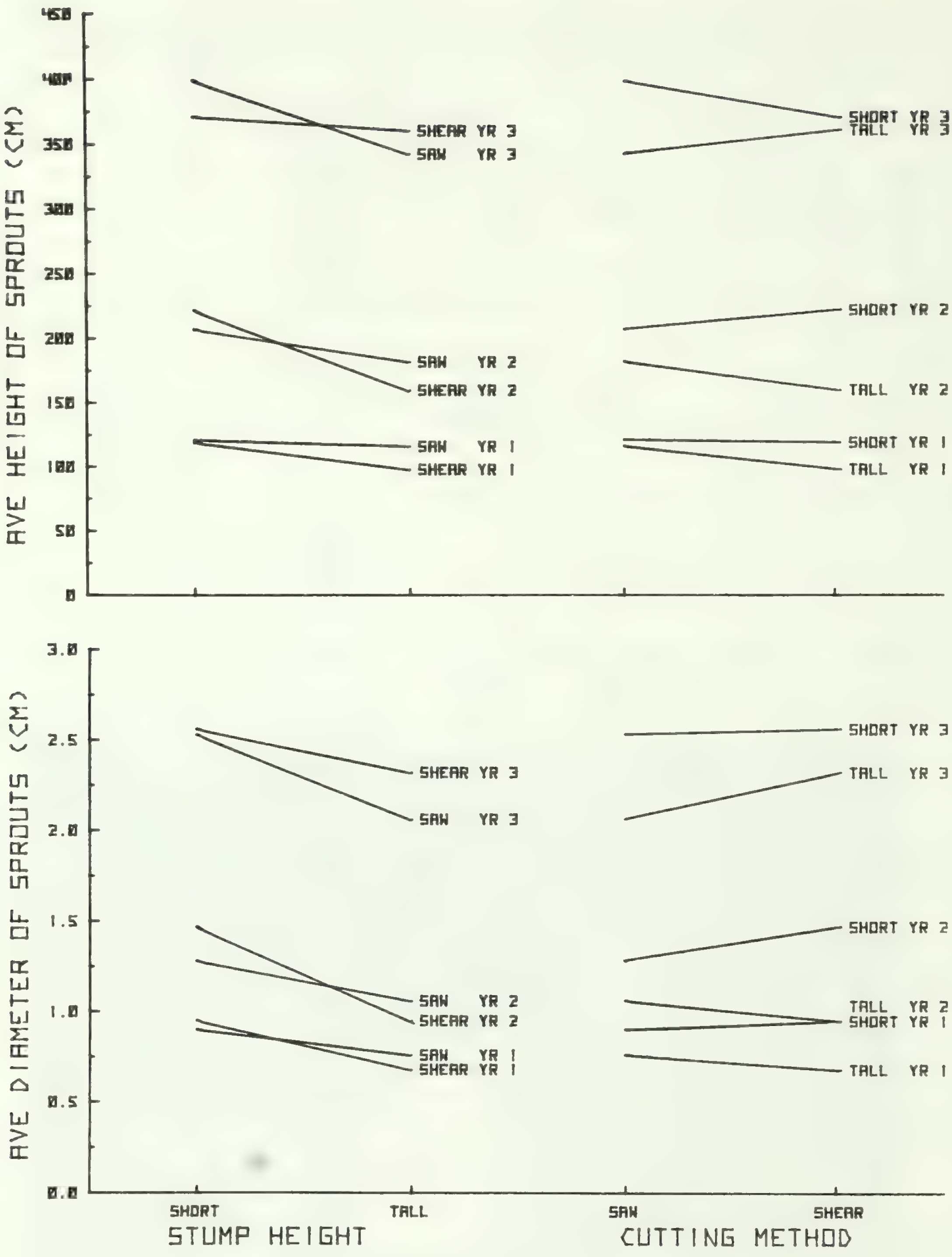

Figure 3.--Average sprout height and diameter for Populus 'Tristis #1' coppice by cutting method and stump height 1, 2, and 3 years after harvest.

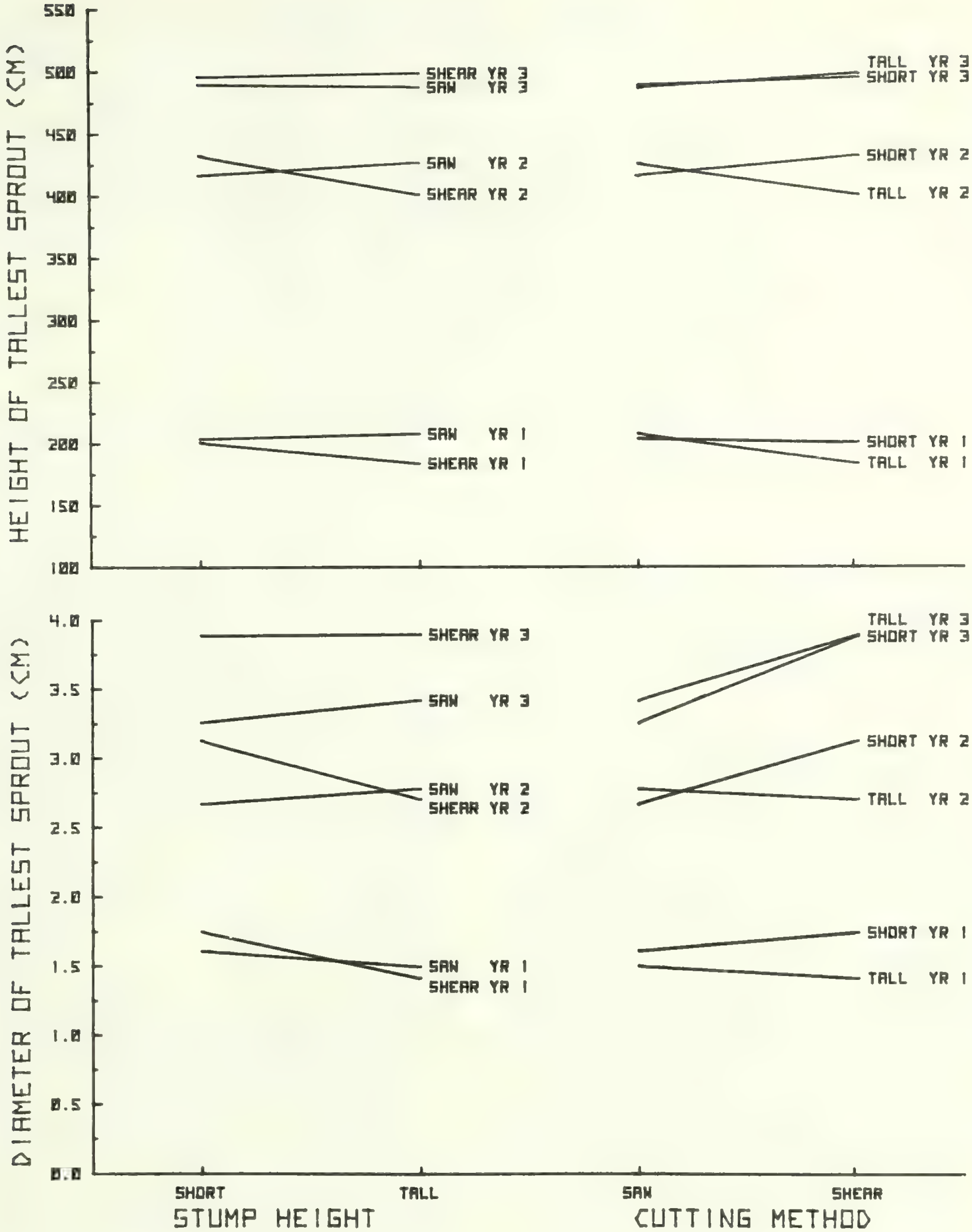

Figure 4.--Height and diameter of tallest sprouts for Populus 'Tristis #1' coppice by cutting method and stump height 1, 2, and 3 years after harvest.

GROWTH AND YIELD OF *POPULUS* COPPICE STANDS GROWN UNDER INTENSIVE CULTURE[1/]

Alan R. Ek, John E. Lenarz, and Albert Dudek[2/]

Abstract.--Growth and survival data on the first three years of development of coppiced stands representing seven clones are described. The data were collected from small multispaced plots at the Rhinelander, Wisconsin, nursery. Sprout growth and mortality equations developed from this data were then integrated with growth and mortality equations developed for older trees of cutting origin to form a simulation model of coppice stand development. Model output suggests potential yields of 5-15 metric tons per hectare per year can be achieved at ages 5-15 years from a variety of spacing and clone combinations under intensive culture. However, there was evidence of considerable variability in results within clones.

Coppicing is a potentially attractive option for short rotation intensive culture (SRIC) of *Populus*. This study was an attempt to estimate that potential for seven clones. The primary objective was to quantify the relationship of coppice stand development to parent stand (before coppice) spacing.

Little information on coppicing was available for the clones considered in this study. Ek and Brodie (1975) presented results for natural aspen stands, primarily *Populus tremuloides* stands. They found site quality, parent and residual stand basal area, season of cutting and cutting treatment had important effects on aspen sucker density. DeBell and Alford (1972) found that stump height and angle of cut had no significant effect on the vigor, size, or number of sprouts produced by *Populus deltoides*. Season of cutting, however, had a significant effect on the number and sizes of sprouts. Stumps cut from September to March produced significantly more sprouts than those cut during the growing season. These authors also noted that stump age may affect vigor and mortality of the sprouts produced. Younger stumps tend to produce sprouts from dormant buds, while sprouts from advantitious buds were prevalent on older stumps. Sprouts from advantitious buds tended to be smaller and more susceptible to wind damage than those produced from dormant buds. Beck (1977) found similar results for *Liriodendron tulipifera* stump sprouts. He also pointed out that thinning sprou to the expected number of crop trees was probably unnecessary because of the competition-induced mortality in such circumstances. In repeated harvesting of *Populus tricocarpa* cuttings planted in the Pacific Northwest, DeBell (1975) noted that spacing had a significant effect on yields for th first harvest, but subsequent coppice stands showed little difference in yields across initial plantings and spacings.

Factors found critical by these authors, whe included in models for initial sprout frequency, growth and mortality, offer the opportunity for i proved screening of superior clones. The specifi

1/ Research supported by the College of Forestry and the Agricultural Experiment Station, University of Minnesota, St. Paul; and the USDA Forest Service, North Central Forest Experiment Station, under Cooperative Research Agreement #13-687.

2/ The authors are Professor, Research Assistant, and former Visiting Scientist, Department of Fores Resources, College of Forestry, University of Minnesota, St. Paul. Dr. Dudek was on leave from the faculty of Forestry, Warsaw Agricultural University, Warsaw, Poland, during part of the project.

bjectives of this study were to analyze available *opulus* coppice stand growth data from the Rhine-ander, Wisconsin, Nursery and: (1) compare lones on the basis of sprouting ability, stand ield, and the relationship of these to parent tand spacings; (2) develop expressions for cop-ice stand growth and yield components; and (3) evelop a computer model integrating this informa-ion on coppice stand development with existing nformation on the development of older stands rown from cuttings.

METHODS

Data

The data for this study were collected from a tudy of various clones established at the Rhine-ander nursery in 1973. Small multispaced plots ere established from cuttings and then harvested t age 4 in December 1977. Each clone was repre-ented by only one plot due to logistical consid-rations at the time. Sample stump locations were ubsequently examined in April 1979, October 1979, nd November 1980 to establish sprout height, dbh nd frequency records. Observations were taken on ll sprouts greater than 0.5 m tall and only prouts within one meter of the parent stump were ncluded. Nearly all sprouts were within 0.5 m f the parent stump. Sprout height and Dbh were bserved to the nearest 0.1 m and mm, respective-y. The number of stumps examined by spacing and pproximate areas per tree were:

pacing (m)	Stumps Observed	Area per tree (m^2)
.3048	3	.0929
.6096	3	.3716
.2192	4	1.4864
.3048 x .6096	3	.1858
.3048 x 1.2192	4	.3716
.6096 x 1.2192	4	.7432

n additional one to four parent stand trees left ncoppiced in the northeast corner of the plot ere also observed for height and dbh growth. hese trees were dominant or codominant stems re-ained to suggest height-Dbh-age relationships for arger trees as a guide to model development. The arent stand plot and sample stump locations are oted in Figure 1. The clones studied are describ-d in Table 1. Note that clones 5258 and 5266 ied during the growing season following harvest-ng and are not considered further here. Also, 260 *Populus Tristis* #1, is included in Table 1 or reference, but it was not among the clones oppiced for this study.

These plots were the same ones described by eldahl (1979) and they continued to receive inten-ive culture fertilization and irrigation treat-ents (see Meldahl, 1979) following the 1977 cop-icing.

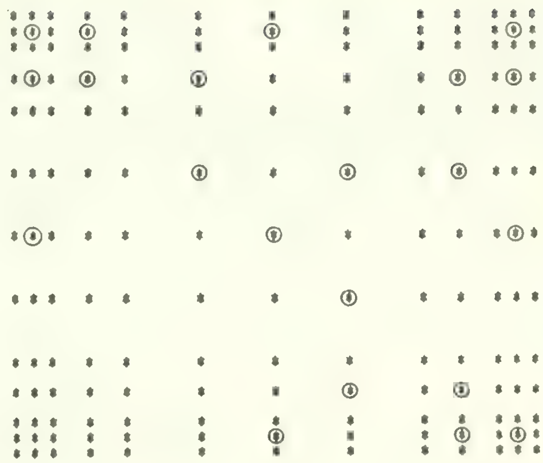

Figure 1.--Multispaced plot design. The narrowest spacing (at each corner) is .3048 m. The widest spacing is 1.2192 m (in the plot center). Parent tree stump locations sampled for sprout data are circled.

Data Analysis and Model Development

Sprout Component

Preliminary analysis of the coppice plot data suggested considerable variability in mortality between clones and years. Average mortality rates across spacings by clone are given in Table 2. The mortality rate of stumps and sprouts was simi-lar and usually the highest for the narrowest spacings, but exceptions to this were frequent. Also, third year mortality (age 2-3) was frequently higher than that for the second year. Results were also confounded by a few small stems growing above the countable height (0.5 m) during the second and third years. Because of this lack of consistency in the pattern of mortality, no simple model fit the data well. Consequently, the mean rates in Table 2 were used for growth model development and projections for all spacings.

As a guide to management, it was noted that the number of sprouts per stump after coppicing was strongly related to the parent stand spacing. Table 3 indicates the number of live sprouts per stump at the end of the growing season following coppicing by clone area per tree.

Table 1.--*Populus* clones studied.

Percentage	Source number	Received from	Supplier's number(s)
Populus spp.	5258	Indian Head, Sask.[1]	---
Populus tristis Fisch. x *P. balsamifera* L. cv. Tristis #1	5260	Indian Head, Sask.[1]	---
Populus cv. Candicans x *P.* cv. Berolinensis	5262	Upper Darby, Pa.[2]	NE-387
Populus cv. Candicans x *P.* cv. Berolinensis	5263	Upper Darby, Pa.[2]	NE-386
Populus cv. Angulata x *P. tricho-* Torr. & Gray	5266	Upper Darby, Pa.[2]	NE-372
Populus nigra L. x *P. laurifolia*	5272	Upper Darby, Pa.[2]	NE-1
Populus x *euramericana* (Dode) Guinier cv. eugenii	5326	Maple. Ontario[3]	DN-34
Populus cv. Betulifolia x *P. trichocarpa* Torr. & Gray	5331	Upper Darby, Pa.[2]	NE-299
Populus cv. Betulifolia x *P. trichocarpa* Torr. & Gray	5332	Upper Darby, Pa.[2]	NE-298
Populus x *euramericana* (Dode)	5377	Ames, Iowa[4]	---

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2/ Northeastern Forest Experiment Station, Upper Darby, PA.

3/ Research Branch, Ontario Div. of Lands and Forests, Maple, Ont.

4/ Forestry Department, Iowa State University, Ames, Iowa.

Table 2. Average sprout mortality rates by clone for coppiced stands.

Clone	Sprout Mortality Rate: Age 1-2 years	Age 2-3 years
	- percent -	
5262	71	63
5263	77	54
5272	63	62
5326	50	64
5331	57	67
5332	17	53
5377	44	56

Table 3. Number of live sprouts per stump at age 1 year following coppicing by clone and parent stand area per stump.

	Parent Stand Area per Stump - m^2				
Clone	.0929	.1858	.6096	.7432	1.4864
5262	4.0	10.5	13.7	20.3	29.0
5263	6.3	5.0	11.3	26.0	27.0
5272	18.0	19.0	17.7	27.2	16.7
5326	1.0	6.8	5.1	6.3	11.8
5331	2.7	11.0	12.3	16.5	25.5
5332	0.7	8.0	11.7	6.2	13.5
5377	2.0	4.8	5.6	5.5	8.8

As a guide to management, it was noted that the number of sprouts per stump after coppicing was strongly related to the parent stand spacing. Table 3 indicates the number of live sprouts per stump at the end of the growing season following coppicing by clone and area per tree.

The average height and dbh of sprouts over all clones was only weakly correlated (positively) with area per stump at the end of the first year, but the correlation increased greatly the second and third years. The correlation of the maximum observed height and diameters with area per stump was consistently higher than that for mean values. Average heights, and Dbh of sprouts observed the first three years are shown with stems per hectare and biomass values in Table 4. Biomass values were developed from equations given by Ek (1980) for *Populus Tristis* #1 and adjusted for the average specific gravity of stem and branch components of each clone.[3]

Note that the per acre values given in the table assume tree growth was representative of the nominal spacing. In fact, the small plot size and especially the close proximity of the narrowest spacings to the plot edge suggest the yields are

3/ Average specific gravity values were drawn from personal communication of a draft manuscript by J. E. Phelps, J. G. Isebrands and D. Jowett.

'able 4.--Three year development of coppiced *Populus* clones under intensive culture at selected spacings.

:lone-age :square pacing (m))	Height (m)	Dbh (cm)	Number of trees (thousand per ha)	Stem and branch wood dry weight (t per ha)
262 - age 1				
.3)	1.3	.46	431	5.6
.6)	1.1	.36	260	2.1
1.2)	1.3	.42	195	2.0
- age 2				
.3)	3.1	1.46	72	13.0
.6)	3.3	1.10	9	.7
1.2)	2.9	1.50	62	12.9
-age 3				
.3)	6.3	3.50	36	49.9
.6)	dead			
1.2)	5.8	3.29	17	21.1
263 - age 1				
.3)	1.4	.34	682	4.2
.6)	1.3	.45	278	3.4
1.2)	1.5	.55	182	3.3
- age 2				
.3)	3.0	1.50	72	12.5
.6)	4.0	2.10	9	3.5
1.2)	3.2	1.61	62	14.5
- age 3				
.3)	3.8	1.90	72	21.8
.6)	5.6	2.80	9	7.0
1.2)	5.6	3.46	20	29.2
272 - age 1				
.3)	1.3	.42	1,938	20.3
.6)	1.3	.41	413	4.0
1.2)	1.5	.45	109	1.3
- age 2				
.3)	2.8	1.18	466	58.6
.6)	2.9	1.23	170	22.2
1.2)	2.6	1.27	740	11.3
- age 3				
.3)	3.8	2.35	251	181.5
.6)	4.8	2.56	72	54.3
1.2)	5.5	2.74	20	17.4
326 - age 1				
.3)	1.4	.29	108	.4
.6)	1.1	.50	81	1.3
1.2)	1.1	.32	79	.4
- age 2				
.3)	1.7	.50	36	.4
.6)	3.3	1.84	36	11.6
1.2)	2.2	1.25	49	7.0
- age 3				
.3)	dead			
.6)	5.5	3.22	27	32.4
1.2)	5.2	2.93	18	18.2

Table 4.-- continued

Clone-age (square spacing (m))	Height (m)	Dbh (cm)	Number of trees (thousand per ha)	Stem and branch wood dry weight (t per ha)
5331 - age 1				
(.3)	1.6	.47	287	3.7
(.6)	1.6	.54	179	3.5
(1.2)	1.6	.62	172	4.6
- age 2				
(.3)	2.2	.65	73	1.8
(.6)	3.5	1.50	27	5.2
(1.2)	2.7	1.46	103	22.4
- age 3				
(.3)	2.6	.70	36	1.1
(.6)	4.5	2.10	18	8.0
(1.2)	5.7	3.26	30	40.9
5332 - age 1				
(.3)	1.6	.35	72	.4
(.6)	1.6	.60	278	6.2
(1.2)	1.6	.56	91	1.7
- age 2				
(.3)	1.9	.58	72	1.4
(.6)	2.5	1.18	224	26.7
(1.2)	2.5	1.30	86	13.6
- age 3				
(.3)	2.6	.80	36	1.3
(.6)	4.6	2.42	81	49.2
(1.2)	4.4	2.52	35	25.2
5377 - age 1				
(.3)	1.0	.43	215	2.2
(.6)	1.1	.50	108	1.7
(1.2)	1.3	.55	59	1.1
- age 2				
(.3)	dead			
(.6)	4.0	3.40	9	12.4
(1.2)	2.8	1.45	44	8.0
- age 3				
(.3)	dead			
(.6)	6.0	4.20	9	19.1
(1.2)	5.0	3.15	20	22.5

overestimates of what might be attained for large regularly spaced stands (see for example Zavitkovsky, 1981).

The results shown in Table 4 indicates clone 5272 was the most productive at all three ages. Clones 5262, 5331 and 5332 were next best and produced yields similar to each other at all three ages. Unfortunately, the small plot and stump sample sizes and associated variable mortality obscurred the relationship of yields to spacing. Table 5 suggests that parent stand densities of 25,000-50,000 stems per ha were most productive to coppice age 3. Conversely, Table 5 may simply indicate those stumps where survival and growth was high--perhaps due to mortality of nearby stumps. It was thus apparent that meaningful interpretations would require analysis of all of the data. This was done by consideration of models described below.

Table 5. Maximum stem and branch wood yields by clone and spacing for ages 1, 2 and 3 years following coppicing.

Clone	Age 1 - (spacing)	Age 2 - (spacing)	Age 3 - (spacing)
5262	8.7 (.3x.6)	33.5 (.3x1.2)	69.6 (.3x1.2)
5263	8.2 (.3x1.2)	33.4 (.3x1.2)	122.1 (.3x1.2)
5272	20.3 (.3x.3)	58.6 (.3x.3)	181.5 (.3x.3)
5326	2.9 (.3x.6)	11.6 (.6x.6)	32.4 (.6x.6)
5331	12.0 (.3x.6)	40.6 (.3x.6)	94.2 (.3x.6)
5332	7.5 (.3x.6)	41.1 (.3x.6)	92.4 (.3x.6)
5377	4.2 (.3x.6)	19.0 (.3x1.2)	52.2 (.3x1.2)

Given the above data on the coppice plots, the following models were fitted to describe mean sprout height and diameter growth

$$H_s = b_1 (1 - e^{-b_2 A_c})^{b_3} T^{b_4}$$

maximum SE = .76
minimum R^2 = .80

and

$$D_s = b_0 + b_1 H^{b_2} A_c^{b_3} T^{b_4}$$

maximum SE = .23
minimum R^2 = .96

where H_s is mean total height of sprouts (m), A_c is coppice stand age (years), T is stems per hectare in the parent stand, D_s is quadratic mean Dbh of sprouts over 1.37 m tall, and the b_is are constants that differ for each equation. The maximum standard error (SE) and minimum R^2 values across the seven clones from model fitting are also given. Note that although the H_s and D_s observations used for these fits were actually mean values, in later simulation, these models were applied to individual sprouts. Also, the close relationship of sprout height to D_s for the first three years after coppicing precluded the need for an explicit diameter growth equation. The coefficients for these and other models noted below are given by Lenarz and Ek (1983, Appendix 3). Subsequently, these data and equations are refered to as those for <u>sprout</u> growth.

Tree Component

The next step in model development was to synthesize, in equation form, the growth projections to age 20 made for the same *Populus* clones by Meldahl (1979). Meldahl's projections were based upon calibration of the FOREST distance dependent individual tree based stand growth simulation model for trees of cutting origin planted at regular spacings (see Ek and Monserud, 1975, for a general description of the FOREST model). It was felt that the general relationships of growth to density and age in these projections would provide a first approximation of post age three relationships for the development of sprouts from coppiced stands. The projection data used was drawn from Meldahl's tables of 20 year plot interior projections results for each clone for various spacings. Specific tables used were his Appendix 3 Tables 32-39, 45-52, 58-65, 71-78 and for clone 5260, Tables 28, 41, 54 and 67. The following models were then used to describe table values.

$$\Delta H = b_1 (H^{b_2} - b_3 H) A^{b_4} N^{b_5}$$

maximum SE = .17
minimum R^2 = .91

$$\Delta D = b_1 (D^{b_2} - b_3 D) A^{b_4} N^{b_5}$$

maximum SE = .26
minimum R^2 = .95

$$\frac{\Delta N}{N} = b_1 (H^{b_2} + b_3 N^{b_4})$$

maximum SE = .02
minimum R^2 = .88

where ΔH is mean height growth (m), A is stand age N is current stems per hectare, and the b_is are constants that differ for each equation. Unfortunately, Meldahl's tables included only clones 5258, 5260, 5262, 5263, 5266, 5326, 5331, 5332 and 5377. Such tree growth data was not available for clone 5272. Conversely, no sprout data was available for clones 5258, 5260, and 5266. Study of growth patterns and suggestions by J. Zavitkovski[4] then led to the assumption of tree growth model

[4] Personal communication, August 30, 1982.

fits from clone 5377 as a first approximation of the growth of 5272.

Subsequently, the data and equations are referred to as those for tree growth. The tree model coefficients are given by Lenarz and Ek (1983, Appendix 3).

The above equations were then assembled in the form of a small distance independent individual tree based stand growth model called POPGROW (see Lenarz and Ek (1983) for details of this model; Ek and Dudek (1980) describe this type of model in detail). This program reflects coppicing practice and short rotation intensive culture in that it allows input of a list of stems (sprouts), each associated with a particular stump. The sprouts are then grown (projected) to age three by the above equations for coppice stems. Subsequently, their growth is projected by the tree growth equations derived from Meldahl (1979). Growth and yields are described by annual output of mean projected height, Dbh, numbers of trees, basal area, biomass by tree component, total biomass and stem wood volume. The biomass equations used were those by Ek (1980) with adjustments noted earlier for differing specific gravities between clone. The stem volume output is based on a fit of Table 3 from Gevorkiantz and Olsen (1955).

The first projections with POPGROW identified a problem noted by Isebrands *et al.* (1982) and Zavitkovsky (1981, 1982). Comparisons of Meldahl's projections with observed plot values at ages 5, 9 and 10 indicated overestimation of height by approximately 4-6 percent. Diameter estimates from Meldahl were close to an actual value at age 5 but overstimated an actual value by up to 91 percent at age 10. Conversely, Meldahl's model underestimated survival by 4 to 7 percent at ages 5 and 10, respectively. These results were incorporated in POPGROW by reducing predicted sprout and tree height growth by 6 percent and reducing tree Dbh growth (post age 3) by 58 percent. Other adjustments incorporated after trial runs included constraining tree growth at wide spacings and at high basal areas. The first was accomplished by constraining the trees per hectare term in the tree height and Dbh growth to no less than 4445 (corresponding to a spacing of 1.5 m). This was necessary since there was no growth data for spacings beyond 1.2 m and because wider spacings were expected to have near maximum diameter growth that would not increase with further spacing. The other adjustments altered tree Dbh growth for stands with greater than 50 m^2 of basal area by the expression $1 - B/200$ and mortality rates by $1/[1 - B/200]$ where B = basal area - 50. In effect, 250 m^2 was considered a maximum possible stand density for SRIC. Further adjustments including constraining height and Dbh growth to maximum values expected for open grown trees were redundant, i.e., they had little or no effect after the adjustments noted above.

The adjustments to prediction models for Meldahl's growth data were considered appropriate because his original model fit allowed excessive and almost linear extrapolation of early diameter growth. Although the adjustments produced a more realistic pattern of growth, they should still be considered quite speculative, especially beyond age ten years. In particular, the lack of data on the long term diameter growth-density relationship made the adjustment process very subjective.

Analysis of Projections

Projections for the seven coppiced clones to age 15 are given in Table 6. Note that these projections are from observed initial conditions at age one and that they utilize average rather than spacing specific mortality for each clone. Also, they incorporate the model adjustments described in the previous section. Complete tables of projections for each clone and spacing are given in a supplement to this paper.[5/]

Table 6 indicates maximum mean annual increment values for stems and branch wood from 4.6 to 15.6 tons per hectare per year (6.4 - 15.6 excluding clone 5377). It is further significant that such yield projections were obtained for a variety of clones and spacings and that the mean annual increment curves appear to stay near their maximum for several years. It appears that these yields could be obtained early at narrow spacings, but that wider spacings would eventually catch up and usually surpass the narrow. For interpretation, it should be emphasized that there is much variability between spacings in the original data and in the projections. For example, projected yield values for clone 5272 at age 3 are possible, but unlikely for large plots.

These projections should be considered another step in the refinement of earlier reports on SRIC yields by Ek and Dawson (1976) and Meldahl (1979). Present values agree roughly with maximum temperate zone short rotation yields suggested by Cannell and Smith (1980). For clarification, however, it should be understood that the present study projects yields for SRIC populus coppice stands under carefully (but not perfectly) controlled experimental conditions. That is also what was intended by Ek and Dawson (1976) and Meldahl (1979). For large scale operations yields per unit area would likely

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5/ Ek, A. R., J. E. Lenarz and A. Dudek. 1983. Supplemental Growth and Yield Tables for "Growth and Yield of *Populus* Coppice Stands Grown Under Intensive Culture." University of Minnesota, College of Forestry. Mimeo. 29 p. Available upon request.

be at least 15-20 percent lower. That shortfall would be due to variability in environmental factors and greater difficulty in applying cultural practices uniformly. Without intensive culture, the yields would be substantially lower.

Table 6. Fifteen year projections of coppice stand development and mean annual stem and branch wood yield for selected *Populus* clones and parent stand spacings.

	Parent Stand Spacing (m)[1]												
	.3 x .3				1.2 x 1.2				2.4 x 2.4				MAI
Age	H	Dbh	N	MAI	H	Dbh	N	MAI	H	Dbh	N	MAI	Range
Clone 5262													
3	4.4	2.2	47	7.5	4.4	2.2	22	3.1	4.4	2.2	5	0.8	
5	6.2	3.0	34	6.8	6.6	3.2	18	4.2	7.3	3.9	5	1.9	
10	10.2	5.2	19	7.2	11.3	5.9	13	6.6	14.0	8.8	5	6.0	
15	13.4	7.5	13	8.2	14.9	8.8	10	8.8	18.2	13.6	4	10.5	8.2-10.
Clone 5263													
3	4.3	2.1	74	10.2	5.1	2.9	20	5.7	5.5	3.2	5	1.9	
5	6.0	2.9	46	7.9	7.6	4.2	17	7.5	8.4	5.6	5	4.2	
10	9.7	4.8	23	7.1	12.5	7.6	12	11.0	15.1	11.6	4	10.7	
15	12.9	7.0	15	7.5	16.0	10.6	9	12.5	19.0	16.8	4	15.6	7.5-15.
Clone 5272													
3	4.0	1.8	272	39.5[2]	4.9	2.3	15	2.7	5.4	2.6	4	0.9	
5	5.0	2.3	80	8.8	7.2	3.4	14	3.7	8.4	4.1	4	1.6	
10	8.1	4.1	33	7.3	12.4	6.3	11	6.5	14.6	8.1	3	3.8	
15	11.0	6.2	20	8.0	15.6	9.4	8	9.3	18.3	12.2	3	6.4	6.4-9.3
Clone 5326													
3	3.9	2.0	19	2.3	4.1	2.2	14	2.1	4.4	2.4	4	0.7	
5	5.9	2.8	17	3.0	5.4	3.2	13	3.0	7.4	4.0	3	1.4	
10	10.2	5.1	13	4.8	11.1	5.8	10	5.2	13.7	8.6	3	4.1	
15	13.5	7.6	10	6.7	14.6	8.6	8	7.5	17.6	13.2	3	7.3	6.7-7.5
Clone 5331													
3	4.4	2.0	41	5.6	5.0	2.5	25	5.8	5.3	2.8	6	1.8	
5	6.2	2.9	31	5.8	7.2	3.6	20	7.0	8.3	4.7	6	3.7	
10	10.1	5.2	18	7.6	11.6	6.6	14	10.3	14.4	9.8	5	9.5	
15	13.3	7.9	13	9.6	14.9	9.7	10	12.8	18.3	14.7	4	15.1	9.6-15.
Clone 5332													
3	4.2	1.9	28	2.8	4.5	2.1	35	4.7	4.7	2.2	9	1.3	
5	6.3	2.9	23	3.9	6.6	3.1	27	5.5	7.6	3.8	8	2.7	
10	11.0	5.6	15	6.7	11.1	5.7	17	8.0	13.7	8.2	7	7.5	
15	14.7	8.6	11	9.5	14.6	8.6	12	10.3	17.7	12.7	6	12.4	9.5-12.
Clone 5377													
3	4.0	2.0	53	6.4	4.3	2.2	15	2.2	4.3	2.2	4	0.6	
5	5.6	2.7	39	6.1	6.6	3.3	13	3.1	7.3	3.6	4	1.0	
10	9.2	4.8	23	6.8	11.4	6.1	10	5.4	13.5	7.3	3	2.6	
15	12.3	7.0	16	8.1	15.0	9.1	8	7.8	17.5	11.2	3	4.6	4.6-8.1

1/ Definition of terms:

H = mean total height (m)
Dbh = mean Dbh (cm)
N = stems per ha (thousands)
MAI = mean annual stem and branch wood increment (metric tons per hectare per year)

2/ An extreme example of data and projection variability.

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PROJECTED AND ACTUAL BIOMASS PRODUCTION OF 2- TO 10-

YEAR-OLD INTENSIVELY CULTURED POPULUS 'TRISTIS # 1'

by

J. Zavitkovski[1]

Abstract.--Intensively cultured plantations of Populus 'Tristis # 1' produce more than 10 mt/ha/year of woody biomass at most spacings as long as they are harvested when mean annual biomass increment (MABI) culminates. In addition, fully stocked plantations produce up to 4.4 mt/ha of leaf litter. Plantations of other poplar clones produce about 30% more woody biomass, but leaf litter production is about the same as in P. 'Tristis # 1'. Because projected biomass productions of P. 'Tristis # 1' were 42 to 182% higher than the actual productions, caution must be exercised when using projected production values. The discrepancy increased with age. P. 'Tristis # 1', although less productive than several other poplar clones in our tests, showed no major deficiencies in 12 years of experimentation. Various P. x euramericana clones have suffered sun scalding in northern Wisconsin, and other clones, including the highly productive NE-299 (NC-5331), have suffered wind damage. P. 'Tristis # 1' should be officially recommended for planting in the Lake States.

Populus 'Tristis # 1', a hybrid between P. tristis Fisch. and P. balsamifera L.,[2] was among the first hybrid poplars included in the short-rotation intensive culture (SRIC) studies at the Forestry Sciences Laboratory (FSL) in Rhinelander, Wisconsin (USDA Forest Service 1976). Plantings were established in the FSL nursery in 1970 and again in 1973 at spacings ranging from 0.23 x 0.23 to 2.4 x 2.4 m (9 x 9 in to 8 x 8 ft). In 1974, an additional planting was established at 3.6 x 3.6 m (12 x 12 ft). In 1976/77, large plantings (0.25 ha or 0.6 acre) of Tristis and three other clones were established on the Harshaw Forestry Research Farm near Rhinelander (Hansen et al. 1979). Many poplar hybrids have been introduced and tested since 1970, but Tristis is still considered among the most promising clones for this part of the Lake States.

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[2]Hereafter Tristis

Growth and production data for the 1970 plantings were summarized and published by Dawson and co-workers (Crist and Dawson 1975, Dawson et al. 1976, Ek and Dawson 1976a, b, and Zavitkovski et al. 1976). Results of the 1973 studies were published by Meldahl (1979). Studies on the utilization potential of 5-year-old Tristis were published by Isebrands et al. (1979).

Serious problems often arise when biomass production estimates are based on small plots with unplanted borders (Zavitkovski 1981a). For example, the biomass production of over 20 mt/ha/year predicted by Ek and Dawson (1976a, b) for Tristis may have been far too optimistic. The objectives of this report are to:

(1) summarize the actual growth and biomass production of all available Tristis plantings at Rhinelander during the first rotation phase[3], and

(2) compare the actual growth and aboveground biomass production with the predicted values of Ek and Dawson (1976a, b) and Meldahl (1979).

[3]First rotation phase refers to plantations established from cuttings.

METHODS

In each plantation, height and DBH were measured annually in the fall or winter. In the 1973 FSL nursery plantings, a "harvest area," consisting of about one-sixth of the total area, was designated for destructive sampling. In the large plantings on the Harshaw Forestry Research Farm, 16 permanent plots were randomly selected in each planting and DBH's in each plot were measured annually. Destructive sampling for biomass estimation was conducted in other parts of the plantings. After all non-destructive measurements were taken, the trees were divided into five or six DBH classes; one tree was randomly selected and harvested from each DBH class. Trees were cut at ground level and height was measured on the ground with a tape; trees were then separated into components and taken to the laboratory for further processing.

In the laboratory, bark was stripped from a subsample of stems and branches and all materials were dried at $70^{\circ}C$ to constant weight. Dry weights were used to develop regression equations suitable for estimating the biomass of all trees in a plot. The biomass of all Tristis plantings was estimated by means of Ek's (1980) equations based on both the DBH and height. Biomasses of other poplar hybrid plantings from age 2 to 6 were estimated by means of allometric equations, based on DBH alone, which were developed separately for each clone and spacing. Biomass of each planting was expressed per unit land area (hectare or acre).

Biomass production of Tristis plantings, expressed as mean annual biomass increment (MABI) in mt/ha/year, is presented separately for the woody parts (stems and branches with bark) and foliage. For comparison, MABI's of several other poplar hybrids planted at the Harshaw Forestry Research Farm in 1976/77 are also presented.

RESULTS AND DISCUSSION

Woody Biomass

For the first few years, the Tristis plantations with close spacing were more productive than those with wider spacing, but with the increasing age, the MABI's of the more open plantings caught up and reached about the same production (Table 1). For example, at age 5 the MABI's of the 0.3 x 0.3 and 0.6 x 0.6 m (1 x 1 and 2 x 2 ft) plantings were 9.9 and 8.9 mt/ha/year, respectively. By comparison, the MABI of the 2.4 x 2.4 m planting was only 3.7 mt/ha/year at age 5, but at age 10 it had reached 10.4 mt/ha/year. We don't know what MABI's would have developed in the two denser plantings by age 10. They were removed at age 6 when they were found unsuitable for further biomass studies mainly because of a pronounced edge effect (Zavitkovski 1981a).

Shape of the growth curves suggests that woody biomasses of the 2.4 x 2.4 and 3.6 and 3.6 m plantings will continue increasing beyond their present levels. Their MABI's may culminate between 12 and 20 years.

Table 1.--Aboveground woody biomass production of 2- to 10-year-old Populus 'Tristis #1' at various spacings[1]

AGE	(IN MEAN ANNUAL BIOMASS INCREMENT - MABI)						
	SPACING (m)						
Yrs.	0.3x0.3	0.6x0.6	1.1x1.1[2]	1.2x1.2	2.0x2.0[2]	2.4x2.4	3.6x3.6
	mt/ha/year						
2	3.7	1.9	1.6	1.1	0.2	0.2	0.1
3	7.0	4.9	3.3	2.3	.9	.6	.3
4	9.0	7.9	6.0	5.1	3.8	2.3	1.0
5	9.9	8.9	6.5	6.8	5.5	3.7	1.7
6	-	-	9.6	-	9.1	4.8	3.2
7	-	-		-		6.5	4.8
8	-	-		-		8.4	5.6
9	-	-		-		9.7	6.2
10	-	-		-		10.4	

[1]Data for the 2- to 5-year-old stands at the Forestry Sciences Laboratory Nursery were adapted from Meldahl (1979). Data for the remaining stands were based on our measurements. Biomass of Populus 'Tristis # 1' was calculated according to Ek (1980).

[2]Plantings at the Harshaw Forestry Research Farm. All data based on our measurements.

It appears that similar MABI's may be reached in SRIC poplar plantations that were established at various spacings as long as they are harvested when their MABI culminates. Similar principles have been proposed for volume production by Moller (1945), Assmann (1953), and Ek and Brodie (1975), and for biomass production by Hutnik and Hickok (1967).

It is important to note that although they may be similar in terms of sustained annual production, the dense and open poplar plantations will feature very different stand structures -- i.e., many slender sapling-like trees/ha in dense plantations and a few large trees/ha in the open plantations. The manager (or economist) can select the best system.

One biological factor to consider when deciding stand density and rotation length will be the average tree size in the final harvest and its ability to coppice. It is possible that coppicing of large trees will be inhibited, preventing successful regeneration. Our present knowledge on coppicing of hybrid poplars in relation to age and size of the tree is inadequate.

At the Harshaw Forestry Research Farm, the age-6 MABI of clone NE-299 (NC-5331) was about 30% higher than that of Tristis, which was in turn substantially higher than the MABI's of two P. x euramericana clones (DN-34 or NC-5326, and NC-5377 cv. Wisconsin # 5) (Table 2). Moreover, the Tristis plantings were healthiest, had better form, and were less susceptible to wind and sun damage than the other clones.

Leaf Litter Biomass and LAI

Compared with natural stands of various broadleaved species of the temperate zone, the intensively cultured Tristis plantations produce substantially more leaf litter and LAI.

Leaf litter production, like the MABI's of woody parts, was strongly affected by stand density during the early years of plantation development (Table 3). Leaf litter quantities of over 4 mt/ha were collected in dense plantings during the first 5 years and similar quantities several years later in the open plantings. The data suggest that 4.4 mt/ha may be the upper limit of leaf litter production in Tristis regardless of spacing (Zavitkovski 1981b). This level was reached in the 2.4 x 2.4 m planting at age 8 (Table 3). In general, leaf litter production showed little annual variation, a finding consistent with the MABI data discussed in the preceding section (Table 1).

Cumulative leaf area index, LAI, essentially followed the same trend as leaf litter production (Table 3). The highest cumulative LAI's were reached at age 6 in plantings spaced from 0.3 x 0.3 to 1.2 x 1.2 m (1 x 1 to 4 x 4 ft), and 1 year later in the 2.4 x 2.4 m (8 x 8 ft) planting. The uniformity of LAI's over a period of 6 years, except for minor unexplained variations (e.g., LAI 5.7 at age 9), is consistent with that found in the leaf litter production.

Leaf litter production and LAI's from 2- to 6-year-old hybrid poplar plantings on the Harshaw Forestry Research Farm were similar to those reported for Tristis (Table 4). In only one instance, the 0.7 x 0.7 m NE-299 (NC-5331) planting at age 4, did leaf litter production (5.2 mt/ha) exceed the highest (4.4 mt/ha) level for Tristis (Table 3). In general, the LAI's were also similar to those of Tristis.

Comparison of Actual and Predicted MABI's

The MABI's projected by Ek and Dawson (1976 a, b) and Meldahl (1979) for Tristis were considerably higher than the actual measured values. This pattern was also documented for the 1.2 x 1.2 m (4 x 4 ft) 5-year-old Tristis planting that had to be harvested because of wind damage (Isebrands et al. 1982). In that study, the aboveground biomass of the planting, excluding leaves, was 37.92 mt/ha, and the woody MABI was 7.6 mt/ha/year (Isebrands et al. 1979). The projected woody biomass and woody MABI were 53.8 mt/ha and 10.8 mt/ha/year, respectively (Ek and Dawson, 1976a, b), or about 42% higher than the actual.

Table 2.--Aboveground woody biomass production of 2- to 6-year-old hybrid poplars at various spacings at the Harshaw Forestry Research Farm (In mean annual biomass increment - MABI)

AGE	SPACING (m) AND CLONE							
	0.7x0.7	1.1 x 1.1			2.0 x 2.0			
	NE-299 NC-5331	NE-299 NC-5331	NC-5260	NC-5377	NE-299 NC-5331	NC-5260	NC-5377	DN-34 NC-5326
	mt/ha/year							
2	2.2	1.4	1.6	0.7	0.7	0.2	0.2	0.2
3	5.8	4.5	3.3	2.5	2.7	.9	.6	.5
4	8.2	7.0	6.0	4.0	5.7	3.8	1.6	1.3
5	8.7	-	6.5	4.5	7.3	5.5	3.7	1.7
6	12.3	-	9.6	8.4	12.1	9.1	6.2	4.6

Table 3.--Leaf litter biomass and leaf area index (LAI) of 3- to 10-year-old *Populus* 'Tristis #1' at various spacings[1]

AGE	SPACING (m)					
	0.3x0.3	0.6x0.6	1.1x1.1[2]	1.2x1.2[3]	2.0x2.0[2]	2.4x2.4
			LEAF LITTER DRY WEIGHT (mt/ha)			
3	3.3	3.2	2.3	2.6	0.7	1.6
4	4.0	4.1	4.1	3.2	1.8	2.5
5	3.4	3.4	3.5	-	3.0	2.5
6	4.2	4.2	3.7	-	3.6	3.4
7	-	-	-	-	-	3.9
8	-	-	-	-	-	4.4
9	-	-	-	-	-	3.6
10	-	-	-	-	-	4.0
			LEAF AREA INDEX (LAI)			
3	6.0	5.6	3.8	4.9	0.6	1.6
4	6.9	7.1	7.3	5.9	1.6	3.2
5	-	7.3	6.1	-	5.7	-
6	8.6	8.7	7.8	-	8.2	6.8
7	-	-	-	-	-	8.4
8	-	-	-	-	-	7.5
9	-	-	-	-	-	5.7
10	-	-	-	-	-	8.3

[1]Data for 3- to 7-year-old stands, except for stands at the Harshaw Forestry Research Farm, are from Zavitkovski (1981b).

[2]Stands at the Harshaw Forestry Research Farm were established in 1976/77. All other stands were established in 1973 at the Forestry Sciences Laboratory Nursery.

[3]Stand was damaged by wind and harvested in 1977.

Table 4.--Leaf litter biomass and leaf area index (LAI) of 3- to 6-year-old hybrid poplar plantations at various spacings[1]

AGE	SPACING (m) AND CLONE							
	0.7x0.7	1.1x1.1			2.0x2.0			
	NE-299 NC-5331	NE-299 NC-5331	NC-5260	NC-5377	NE-299 NC-5331	NC-5260	NC-5377	DN-34 NC-5326
				LEAF LITTER DRY WEIGHT (mt/ha)				
3	3.0	2.4	2.3	1.5	1.7	0.7	0.6	0.4
4	5.2	4.4	4.1	3.2	4.4	1.8	1.4	1.4
5	4.4	lost[2]	3.5	2.6	2.6	3.0	2.0	1.8
6	4.3	-	3.7	3.1	3.9	3.6	2.7	2.9
				LEAF AREA INDEX (LAI)				
3	5.7	6.2	3.8	1.5	3.5	0.7	0.8	0.7
4	7.3	8.5	7.4	2.6	6.6	1.7	1.4	2.0
5	6.9	lost[2]	6.2	3.4	4.4	5.7	2.6	2.1
6	7.0	-	7.8	5.1	6.1	8.2	3.9	4.1

[1]Plantations at the Harshaw Forestry Research Farm

[2]Stand was damaged by windstorm and harvested.

The actual MABI of the 10-year-old, 2.4 x 2.4m Tristis planting was 10.4 mt/ha/year (Table 1). Ek and Dawson's (1976a, b) projection was 96% higher (20.4 mt/ha/year) and Meldahl's (1979) projection, based in part on data from the 1973 plantations, was 81% higher (18.8 mt/ha/year) (Table 5). The actual MABI of the 9-year-old, 3.6 x 3.6 m Tristis planting was 6.2 mt/ha/year, whereas Ek and Dawson's projection for a slightly more widely spaced planting (3.9 x 3.9 m) was 182% higher (17.5 mt/ha/year).

Table 5.--Comparison of predicted and actual survival, growth, and biomass production of 9- and 10-year-old Populus 'Tristis #1'

DATA	SURVIVAL		DIAMETER		HEIGHT		MABI[1]	SOURCE
	Trees/ha	%	cm	in	m	ft	mt/ha/year	
10-YEAR-OLD, 2.4 x 2.4 m (8 x 8 ft) PLANTING								
Actual	1,626	97	9.8	3.9	13.5	44	10.4	Present study
Predicted	1,556	93	26.7[2]	10.5	16.2	53	20.4	Ek and Dawson (1976a,b)
Predicted	1,510	90	18.7	7.4	13.7	45	18.8	Meldahl (1979)
9-YEAR OLD, 3.6 x 3.6 m (12 x 12 ft) PLANTING								
Actual	716	96	10.1	4.0	12.0	39	6.2	Present study
Predicted	625	93	35.8[2]	14.1	15.5	51	17.5	Ek and Dawson (1976a,b)[3]

[1]Mean annual biomass increment, MABI.

[2]Diameter at 2.5 cm (1 in) above-ground.

[3]Projected for a 3.9 x 3.9 m (12.7 x 12.7 ft) planting.

In summary, models used for estimating biomass production of intensively cultured poplar plantations have consistently overestimated actual growth. Although numerous factors may have contributed to these overestimates (see Isebrands et al. 1982), the results of this study suggest that biomass projections based upon limited data from small plots should be used with caution.

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YIELD PHYSIOLOGY OF SHORT ROTATION INTENSIVELY CULTURED POPLARS

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Abstract.--An integrated research approach is described for studying yield physiology of short rotation intensively cultured (SRIC) poplar plantations. Branch architecture differs with clone and stand density, but the clonal ranking of important branch characteristics does not change with spacing. Crown morphological variables have a distinct effect on physiological properties of leaves within the crown. Such variables as leaf age, position, shoot type, and distance to the main stem are all important. Leaf area is linearly related to biomass production in the first 5 years of SRIC plantations. Photosynthetic rate (PgA) is strongly influenced by differences in leaf orientation in the crown. Diurnal patterns of PgA also differ with position in the crown and light climate. PgA is high in clones that exhibit significant autumal green leaf retention. Clones differ distinctly in photosynthate distribution patterns. Both timing of budset and leaf fall are important factors determining these patterns. Current terminal leaves provide most of the photosynthate used for height growth; mature leaves on the upper branches contribute primarily to stem diameter and root growth. Clones with high late-season PgA's also show substantial production of photosynthate, which is exported to the stem and roots. Growth analysis conducted in conjunction with photosynthesis and photosynthate distribution studies led to a better understanding of growth patterns. Stem dry matter production paralleled leaf production during the course of the season. Clones differ in root/shoot ratio during the establishment year so both above- and below-ground growth data are needed to evaluate clonal performance in that year. Silvicultural and genetic implications of the data are discussed and recommendations are given for practical applications of the results. The current understanding of a superior "ideotype" for a SRIC poplar tree is also given.

Basic physiological and genetic investigations of yield have allowed agronomists and horticulturists to improve the productivity of several important crops (Coyne 1980; Evans 1980; Boyer 1982). Fundamental research information has been used to identify which physiological characteristics (or criteria) of the crop are important in determining the efficiency of energy conversion to harvestable yield. Those criteria with high heritability are then used by the plant breeder to choose parents for a breeding program.

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Physiological data have also been successfully used to identify the critical stages of plant development; then plant varieties can either be identified or developed that perform well at those critical stages (Freeman 1975). Unfortunately, the complex physiological characteristics correlated with crop yield are often interrelated (Nasyrov 1978) and controlled by multigene systems (Wallace et al. 1976). As a result of this complexity the most successful programs for improving crop yield have been those that utilized the cooperative talents of plant breeders, crop physiologists, and plant biochemists.

The most common approaches to increasing productivity in crops are: 1) optimizing canopy structure, 2) improving photosynthetic rates, and 3) partitioning a large proportion of the total assimilates into yield (harvest index) (Nasyrov 1978). These approaches can also be applied toward increasing productivity of trees because many of the theoretical and conceptual principles of yield are fundamentally similar between cultivated crops and trees (Larson 1969; Ledig 1975; Borlaug 1977).

In 1978 we began a research program designed to provide physiological criteria for improving short rotation intensively cultured (SRIC) poplars. Our goal was to obtain baseline morphological and physiological information on poplar trees grown in the field. An integrated research approach was selected to obtain the baseline information on similar trees. Integrated studies of crown morphology, photosynthesis, and photosynthate distribution were conducted in relation to biomass yield as expressed by traditional growth analysis (see Evans 1972). Studies in each scientific discipline were coordinated so that resultant information would be compatible. Research was conducted each year for 4 years on several clones, beginning with the establishment year. Our philosophy was that detailed physiological data on a few representative clones would be more valuable at the early stages of the research program than scattered data on many clones. We believe that such baseline information can also eventually be applied (within limits) toward the understanding of the physiology of some other promising clones. Studies of the few selected clones were also designed to extend baseline physiological data developed on trees grown in controlled environments and in the greenhouse to trees grown in the field. Information from the field experiments was used to plan further laboratory studies. We hoped that an understanding of baseline physiological mechanisms in field-grown poplars would help explain results of various field tests of establishment and growth. We also hoped that a biological explanation of yield would give forest managers more confidence in selecting clones and choosing cultural practices (Ledig 1975).

The objectives of this paper are to summarize and explain the results to date of our integrated research and to discuss the silvicultural and genetic implications of these results. These morphological and physiological data will also be used to describe what the "ideal" poplar clone (i.e., ideotype; Donald 1968) might be for certain SRIC systems.

The following clonal materials were studied: 1) Populus tristis x P. balsamifera cv. 'Tristis #1' (NC-5260) and P. x euramericana cv. 'Eugenei' (NC-5326)[2/] trees grown in pots for one growing season in both controlled environments and the field (Nelson and Ehlers 1981; 1982); 2) the same two clones grown under SRIC at 0.6 m specing for 4 years; 3) Tristis grown at 1.2 m and 0.6 m spacings for 5 and 6 years (Isebrands and Nelson 1982); 4) P. nigra cv. betulifolia x P. trichocarpa (NE-298) and NC-9922, (probably P. deltoides x P. trichocarpa) grown for 4 years at 1.2 m spacing under a gradient of cultural practices; and 5) P. nigra x P. laurifolia cv. 'Strathglass' (NE-1) grown under SRIC at several spacings for 2 years (Nelson et al.1980 b,c). Details of the establishment and culture of the SRIC poplar clones are given elsewhere (Nelson et al. 1981, Isebrands and Nelson 1982, Nelson and Michael 1982, Nelson et al. 1982).

CROWN ARCHITECTURE AND CANOPY DENSITY

Solar energy is the driving force of all photosynthetic processes. Thus, biological yield is intimately related to the light-intercepting characteristics of a crop (Wilson 1979). In trees, as in other crops, light interception is strongly influenced by crown architecture and canopy density. Photosynthetic capacity of leaves is also affected by such variables as position in the crown (Michael et al. 1980), shoot type (Nelson and Michael 1982), and specific leaf weight (Nelson and Ehlers 1981, 1982). Moreover, the economic yield of tree crops such as SRIC poplars is strongly influenced by crown characteristics because of their effects on the utilization potential of the raw material (Crist et al. 1979, Isebrands et al. 1979, Phelps et al. 1982a, 1982b). Therefore, the variables we collectively define here as crown architecture and canopy density (i.e., branch architecture, leaf morphology and distribution, leaf area, and leaf orientation) have a major impact on the quantity and quality of yields

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[2/] Hereafter Tristis and Eugenei.

from SRIC poplar plantations.

Branch Architecture.--Many factors affect the sequential growth pattern of a poplar crown. Some of these factors are amenable to genetic and/or silvicultural manipulation whereas others are not (Isebrands 1982). For example, branch characteristics of SRIC poplars differ greatly with clone and stand density (Dawson *et al*. 1976, Isebrands *et al*. 1977, Nelson *et al*. 1980a, 1981). However, the ranking of poplar clones for most branch characteristics does not change significantly at different plantation spacings. This lack of a clone-spacing interaction for branch properties (i.e., branch angle) greatly simplifies genetic selection and breeding for crown architecture in poplar (Nelson *et al*. 1980a, 1981). One illustration of this point is that selected fastigiate genotypes will probably maintain their acute branch angle for a wide range of spacings. Clones with a narrow crown architecture are thought to be advantageous at close spacings because they occupy less space and compete only weakly for light with their neighbors (Burk 1981, Nelson *et al*. 1981).

Branch architecture of poplar clones also differs with each height growth increment (HGI) (fig. 1) and with position within the HGI (Burk 1981; Isebrands 1982; Isebrands and Nelson 1982). The uppermost first-order branches within each HGI are usually the largest, and their length and diameter decrease basipetally (Jankiewicz and Stecki 1976). The order of branching rarely exceeds third-order in SRIC poplar plantations (Isebrands and Nelson 1982), and live branches are commonly shed (cladoptosis) in the lower crown, particularly in Euramericana clones (Nelson *et al*. 1981).

Leaf Morphology and Distribution.--In tree crowns leaves of different age, structure, and size; on different shoot types; and at different distances from the main stem have distinctly different physiological properties (Kramer and Kozlowski 1979). These leaf characteristics have important effects on both photosynthetic rate and on the distribution of photosynthate within the tree in SRIC poplars (Isebrands and Nelson 1980; Michael *et al*. 1980; Nelson and Ehlers 1981, 1982; Nelson and Michael 1982; Isebrands 1982).

SRIC poplars aged 4 and older display their leaves in a complex crown arrangement (fig. 1) encompassing at least three orders of branching and two different shoot types (i.e., long and short shoots)(Isebrands and Nelson 1982). The distribution of leaves, leaf area, and average leaf area per leaf differ with HGI in the tree (table 1). The current terminal

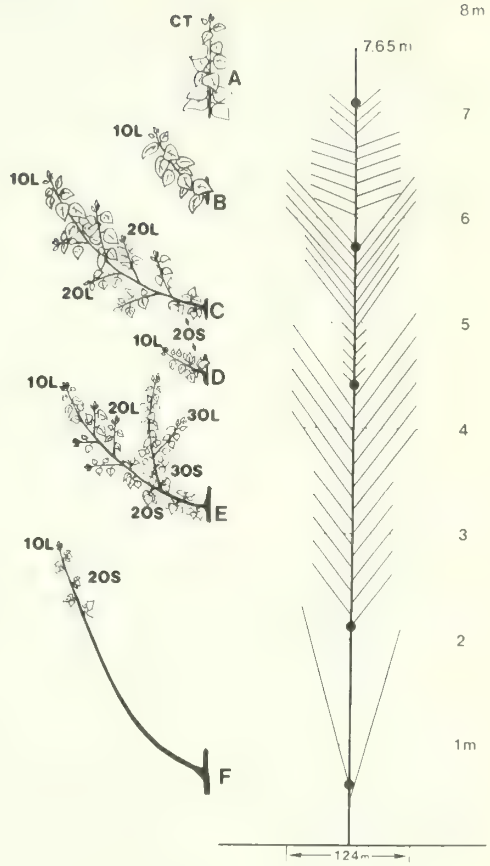

Figure 1.--Schematic of 6-yr-old *Populus* 'Tristis' grown under SRIC. Each dot on main stem delineates the beginning of an annual height growth increment (HGI). Position A is the current terminal shoot (HGI); B is a first-order long shoot (1OL) on HGI 5; C is a first-order branch on HGI 4 with its terminal shoot a long shoot and with second-order long shoots (2OL) and second-order short shoots (2OS); D is a short first-order branch also on HGI 4 with a terminal shoot ((1OL) and with 2OS; E is a first-order branch on HGI 3 with 1OL, 2OL, 2OS, and third-order long shoots (3OL) and third-order short shoots (3OS); and F is a first--order branch on HGI 1 with a terminal shoot (1OL) and 2OS. Branch length and angles are drawn to scale, except that branches in the field curve upward (from Isebrands and Nelson 1982).

shoot on a 5-yr-old tree has less than 1 percent of the total number of leaves and about 1 percent of the total leaf area. However, these

Table 1.--Average number of leaves, leaf area, and leaf area per leaf within the crown of 5-yr-old SRIC Populus 'Tristis' trees grown at 1.2 m spacing[1/] (from Isebrands and Nelson 1982)

Crown position		Leaves/position		Leaf area/position		Leaf area/leaf
HGI[2/]	CT[3/]	No.	Percent Total	cm^2	Percent Total	cm^2
5		29	<1	1,415	1	47
4		414	6	11,685	11	26
	L	282		8,841		31
	S	132		2,844		22
3		1,528	23	32,728	31	16
	L	1,302		28,534		21
	S	226		4,194		14
2		2,239	34	29,645	29	12
	L	1,988		26,927		13
	S	251		2,718		11
1		2,434	37	29,136	28	11
Total		6,644	100	104,609	100	

1/Weighted averages for nonborder trees are based on proportional stratified sampling of the entire stand.

2/HGI=height growth increment; L=branches >0.6 cm basal diameter; and S=branches <0.6 cm basal diameter.

3/Current terminal.

leaves are the largest on the tree and are attached directly to the main stem. In subsequent HGI's the difference between the percentages of total number of leaves and total leaf area increases dramatically, reflecting a decrease in average leaf size from the upper to the lower portion of the crown.

Knowing the distribution of leaves by HGI alone does not provide a complete indication of the crown's light-intercepting ability. Leaves on a given HGI often occur in several vertical strata or light climates because of the upward growth of branches (table 2). For example, 85 percent of the total number of leaves in 6-yr-old SRIC Tristis occur in the three height strata from 4 to 7 m, and those leaves are on branches attached to HGI's 3, 4, and 5. Thus, leaves within a given light climate often contribute photosynthate to several different parts of the main stem. This difference has major physiological importance because lateral branches normally only contribute appreciable quantities of photosynthate to main stem below their point of attachment (Isebrands 1982). Thus, the rapid growth exhibited by some SRIC poplar clones may be related to the high percentage of their leaf area displayed in favorable light-intercepting positions within the crown.

Table 2.--Distribution of leaves within the crown of a 6-yr-old short rotation intensively cultured Populus 'Tristis' tree grown at 0.6 m spacing by vertical height strata and height growth increment[1/] (from Isebrands and Nelson 1982)

Vertical strata	Total number of leaves		Height growth increment 6	5	4	3	2	1
m	No.	Percent	Percent total number of leaves					
7-8	63	4	1	3	-	-	-	-
6-7	539	36	-	16	20	-	-	-
5-6	332	23	-	1	20	2	-	-
4-5	393	26	-	-	6	20	-	-
3-4	108	7	-	-	-	7	-	-
2-3	61	4	-	-	-	3	-	1
<2	-	-	-	-	-	-	-	-
Total	1,496	100	1	20	46	32	-	1

1/Individual tree of average leaf area from subsample.

Although crown position and shoot type are the dominant factors determining leaf size in SRIC poplar clones (Isebrands et al. 1977, Isebrands and Nelson 1982), clonal differences in leaf size are also common (table 3). For example, at the end of 2 years in the field the leaves of NC-9922 were much larger and fewer than NE-298, but total leaf areas of the clones were not significantly different (fig. 2). Clonal differences in specific leaf weight (SLW) are also often substantial; differences in clonal averages may even exceed 20 g.m^{-2} (Isebrands et al. 1977, Gottschalk and Dickmann 1978). SLW usually decreases from the current terminal downward toward the base of the tree (Isebrands et al. 1977, Isebrands and Nelson 1982). In addition, shoot type also has an influence on SLW; long-shoot leaves at similar positions have a higher SLW than short-shoot leaves (Isebrands and Nelson 1982).

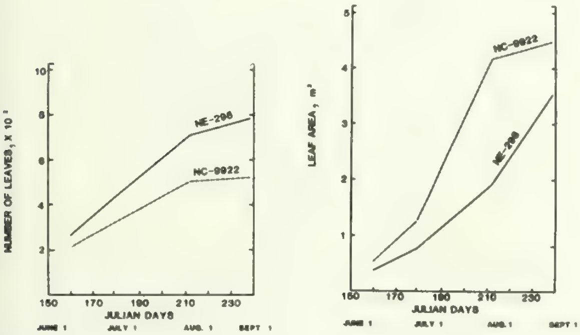

Figure 2.--Seasonal development of number of leaves and leaf area in two, 2-yr-old Populus clones grown under SRIC at 1.2 m spacing (NE-298, P. nigra cv. betulifolia x P. trichocarpa; NC-9922, probably P. deltoides x P. trichocarpa).

The crowns of hybrid poplars grown under SRIC are comprised of a higher ratio of long shoots to short shoots than other poplars (Pollard 1970). The proportion of long and short shoots also differs with clone and age; the proportion of short shoots usually increases as a tree ages (Kozlowski 1971). Five- and 6-yr-old Tristis trees grown under SRIC have 53 to 66 percent of their leaf area on long shoots, with about 95 percent of the long-shoot leaves in the upper three-eighths of the leaf-containing vertical strata. The average long-shoot leaf was 34 cm^2 in area, compared to 19 cm^2 for the average short-shoot leaf (Isebrands and Nelson 1982). The ratio of long shoots to short shoots in a poplar crown has physiological importance. For example, leaves on long shoots of Tristis have higher midseason photosynthetic rates (Nelson and

Table 3.--Seasonal patterns of growth, distribution of leaves, distribution of leaf area, leaf area per leaf, and leaf area index in two, 2-year-old poplar clones grown under intensive culture at 1.2 m spacing

Date1/	Height		Diameter		Distribution of leaves				Distribution of leaf area				Leaf area per leaf				Leaf area index3/	
					Current terminal		Laterals		Current terminal		Laterals		Current terminal		Laterals			
Clone2/	9922	298	9922	298	9922	298	9922	298	9922	298	9922	298	9922	298	9922	298	9922	298
	m		cm at 0.3m		Percent				Percent				cm^2				$m^2 \cdot m^{-2}$	
June 9	1.3	1.3	1.5	1.1	5	3	95	97	8	5	92	95	42	21	25	14	0.4	0.3
June 28	1.6	1.5	2.0	1.5	5	4	95	96	10	6	90	94	74	32	38	23	0.9	0.7
July 31	2.4	1.9	3.0	2.2	6	4	94	96	12	8	88	92	172	52	78	26	2.8	1.3
August 29	3.4	2.9	4.3	3.4	8	5	92	95	25	10	75	90	288	87	70	43	3.0	2.4

1/ The 1978 growing season. Each value is the mean of two replications.
2/ The clones were NC-9922, Populus sp., probably P. deltoides x P. trichocarpa; and NE-298, P. nigra x P. trichocarpa.
3/ Mean tree approach assuming no mortality.

Michael 1982) and contribute more photosynthate for wood production than leaves on short shoots. These observations suggest that the high biomass yields for SRIC poplars may be partially explained by the favorable long-shoot/short-shoot ratio in their crowns (Isebrands and Nelson 1982).

Leaf Areas.--SRIC poplar stands have higher leaf areas than natural stands. Leaf area index (LAI) values for 5- and 6-yr-old SRIC Tristis stands at 1.2 and 0.6-m spacings grown under less than optimum conditions were 7.6 and 8.8, respectively (Zavitkovski 1981, Isebrands and Nelson 1982). In addition, LAI's exceeded 15 in 4-yr-old SRIC Tristis grown at 0.6-m spacing, but these trees were grown in small plots and may have had somewhat inflated LAI's because of greater side light penetration (Isebrands et al. 1977).

Clones often differ greatly in LAI (Isebrands et al. 1977, Gottschalk and Dickmann 1978). Moreover, clones also differ significantly in the time required to develop maximum LAI during a growing season (fig. 2, table 3). For example, in the second year NC-9922 and NE-298 had similar leaf areas at the end of the year but most of NC-9922's leaf area was produced during July and most of NE-298's was produced during August.

The high LAI's of SRIC poplar stands result in leaves making up a large portion of the above-ground biomass. For example, in 5-yr-old Tristis grown at 1.2-m spacings, leaves accounted for 10 percent of the total biomass (Isebrands et al. 1979). Leaf biomass can approach 40 percent in young stands planted at close spacings, but that percentage decreases as stands develop and age (Gottschalk and Dickmann 1978).

Stem volume and above-ground biomass of individual trees in SRIC poplar plantations are linearly related to the total leaf area of the tree (Larson et al. 1976, Isebrands et al. 1977, Isebrands and Nelson 1982). Furthermore, stem growth at any particular height is closely related to the cumulative leaf biomass or leaf area above that point (Tadaki 1966, Larson and Isebrands 1972). Although we cannot yet define an "optimum" LAI for SRIC poplar stands, we predict that it will be at least 10. In the stands we've studied we have found no evidence of excessive LAI's that produce negative effects on growth, which is consistent with data from other crops (Watson 1952, Donald 1961). Attaining "optimum" LAI in the SRIC plantation early in the rotation and maintaining it throughout the rotation is important (Isebrands and Nelson 1982). Based on evidence from agronomic crops (Watson 1952, Loomis and Williams 1963, Moss 1975) we suggest that the ability to rapidly attain high LAI early in the growing season and to maintain that leaf area throughout the growing season (i.e., leaf area duration) are important determinants of rapid growth in SRIC poplar stands. Extended green leaf retention in the autumn, a trait in some SRIC poplars, also contributes substantial photosynthate to late season stem and root growth (Nelson et al. 1980b,c, Isebrands 1982, Nelson et al. 1982).

Leaf Orientation.--Because photosynthesis depends on the amount of light, photosynthetic rate per unit leaf area (PgA, $mgCO_2m^{-2}s^{-1}$) is closely related to the effect that the leaf's three dimensional orientation has on light interception (Michael and Dickmann 1982). The importance of leaf orientation on light interception, PgA, and yield has been studied extensively in agronomic crops (Monteith 1965, Vidovic 1974, Austin et al. 1976), but limited information exists for trees.

As part of our study of light interception in SRIC poplars in the field, we quantified leaf orientation during the first 3 years in two clones: Tristis, which has a horizontal leaf display, and Eugenei, which has a vertical leaf display. Leaf azimuth angle, the vertical angle formed by the leaf's midrib (midrib angle), and the vertical angle formed by a line perpendicular to the midrib in the lamellar plane (lamina angle), were measured using methods developed by Max (1975). In poplar clones leaf display angles are not necessarily related to branch angles of the main tree stem, although leaf azimuth and branch azimuth are related (Burk 1981).

In the first growing season, the azimuth angle of a leaf is strongly controlled by its position along the phyllotactic spiral. Midrib angles in both clones were similar. Eugenei's observed vertical leaf orientation was a result of rotation around the midrib axis, i.e., adjustment of the lamina angle (fig. 3). By comparison, Tristis had a minimal deviation of lamina angle from 90° in contrast to Eugenei; this small deviation gives rise to Tristis' horizontal leaf orientation.

Zenith angle (ZA), the angle between a line perpendicular to the leaf's surface and that line's zenith (high point), provides a useful measure of leaf orientation that incorporates all rotations along a leaf's axis into one variable. When ZA = 0, for example, the leaf is horizontal; ZA values increase as leaves become more vertically oriented. During the first growing season mean ZA's were 50° and 20° for Eugenei and Tristis, respectively, and Eugenei had the widest range of ZA values. The same pattern was also observed within the crowns

of 2-yr-old trees; mean ZA's for Eugenei and Tristis were 54° and 21°, respectively.

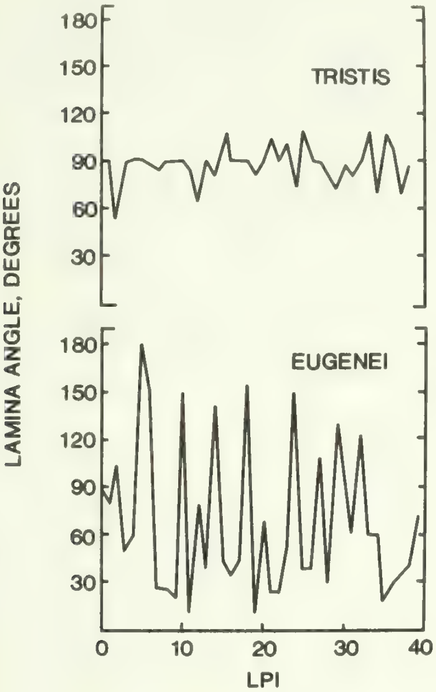

Figure 3.--Lamina angles (the angle between the vertical and a line perpendicular to the leaf midrib in the lamellar plane) for two, 1-yr-old Populus clones (P. tristis x P. balsamifera cv. 'Tristis #1' and P. x euramericana cv. 'Eugenei') by leaf position. LPI 0 (LPI, leaf plastochron index) is the first leaf below the apex attaining a lamina length of 3 cm.

Leaf orientation greatly influenced the distribution of light and photosynthetic activity within the crowns of both clones. Light interception and photosynthesis were concentrated in a few large leaves in Tristis' upper crown due to a high degree of mutual shading in the lower crown. This shading was especially evident after the first growing season. Eugenei's vertical leaf display resulted in less mutual shading and a more even distribution of light and PgA within the crown when compared to Tristis (table 4).

PHOTOSYNTHESIS

Photosynthetic activity varies significantly among the leaves of a poplar tree growing in the field. For example, photosynthesis varies with leaf position, leaf orientation, leaf age, and season.

Table 4.--Within-crown comparison of total leaf area, light interception, and whole-leaf photosynthesis (PgL) for two, 1-yr-old Populus clones[1/]

Clone[2/]	Crown level	Leaf number from base	Leaves	Leaf area	Light interception[3/]	PgL[3/]
			Number	cm^2	μ moles s^{-1}	mg CO_2 s^{-1} x 10^4
Tristis	A	31 - 34	4	148	15 (14)	80 (9)
	B	21 - 30	10	547	60 (54)	470 ([illegible])
	C	11 - 21	10	362	26 (24)	[illegible] ([illegible])
	D	1 - 10	10	177	9 (8)	[illegible] ([illegible])
		TOTAL	34	1,234	110	[illegible]
Eugenei	A	30 - 31	2	53	1 (1)	[illegible] (<1)
	B	20 - 29	10	625	37 (38)	[illegible] (4[illegible])
	C	11 - 19	9	489	34 (35)	[illegible] (3[illegible])
	D	1 - 10	10	310	26 ([illegible])	[illegible] (2[illegible])
		TOTAL	31	1,477	[illegible]	[illegible]

1/ Leaves were measured on 8-8-79.
2/ Clones were Tristis - P. tristis x P. balsamifera cv. 'Tristis #1', and Eugenei - P. x euramericana cv. 'Eugenei'.
3/ Values in parentheses are percent of total light interception or PgL.

Establishment Year.--The rate of photosynthesis and the quantity of photosynthate produced by a poplar tree during the first growing season in the field is largely determined by how effectively its leaves capture and utilize available light.

Field measurements within poplar crowns show that single leaf PgA varies greatly due to differences in light interception and leaf age (fig. 4). The net effect of leaf position, leaf orientation, and leaf age on whole-crown photosynthetic rates can be best assessed by measuring photosynthetic rates of leaves in their natural orientation, and then expressing photosynthesis and light interception on a whole-leaf basis for different regions of the crown. This approach allows comparisons to be made between different crown levels within a clone and among different clones.

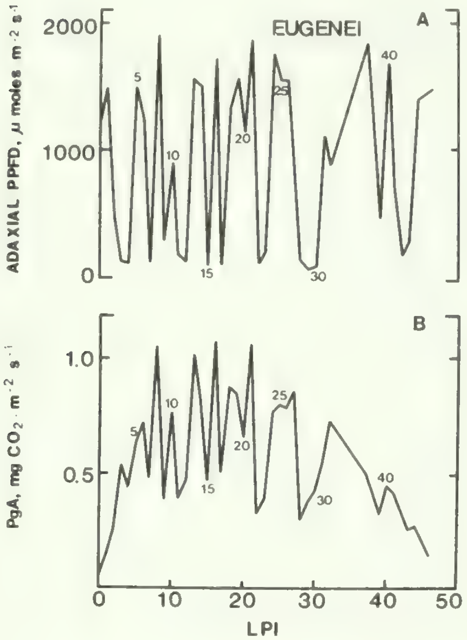

Figure 4.--Adaxial photosynthetic photon flux density (PPFD) and photosynthetic rate (PgA) for a 1-yr-old P. x euramericana cv. 'Eugenei' tree (46 leaves) measured in the field beginning at 10:00 solar time, August 30, 1979.

During the establishment year, leaf area, light interception, and photosynthesis on a whole-leaf basis (PgL, $mgCO_2 s^{-1}$) in both Tristis and Eugenei reached a maximum in the upper-middle crown (level B, table 4). Light interception and PgL in the B level was greater in Tristis than in Eugenei, even though Tristis had less leaf area at that level. This difference is a direct result of clonal variation in leaf display (i.e., light interception strategies).

Tristis' horizontal midcrown leaves capture more light than Eugenei's vertical midcrown leaves, especially when the sun's altitude is high during mid-afternoon. But Eugenei's leaf display produces less mutual shading and allows more light to penetrate to the lower crown levels during mid-day. As a result, both light interception and photosynthetic rates are more evenly distributed throughout Eugenei's crown than in Tristis' (table 4). Note that the two lower crown regions (levels C and D) accounted for 32 and 61 percent of the tree's total intercepted light and 36 and 57 percent of the total crown photosynthesis for Tristis and Eugenei, respectively.

Light interception and photosynthesis in Tristis are concentrated in a few young and highly productive horizontal leaves located in the upper-middle crown. Diurnally these leaves attain maximum illumination at mid-day when they are close to or above photosynthetic light saturation, and most of the intercepted light is concentrated on the upper-leaf surface. Moreover, Tristis leaves reach a higher PgA at light saturation than Eugenei leaves; thus, Tristis leaves can utilize high light intensities better than Eugenei. By contrast, maximum light interception occurs in Eugenei in late morning and late afternoon when the sun is at oblique angles to the tree. Light interception during these peak period occurs on both the upper and lower leaf surfaces. Thus, available light is efficiently utilized because a large number of leaves are illuminated. However, leaves in the lower crown of Eugenei must be photosynthetically responsive to illumination below light saturation in order to benefit from this pattern of light dispersal.

Another difference between the two clones in the first growing season is that the contribution of the lower crown declines rapidly in Eugenei late in the growing season as its leaves senesce. In Tristis the lower crown region remains productive throughout most of the season.

Despite the differences in patterns of light interception, Tristis and Eugenei are about equal in overall photosynthetic efficiency (PE, $mgCO_2$ fixed/μmole of light photons) for the first growing season. At mid-season PE was 7.9 and 8.3 x 10^{-4} mg CO_2 $\mu mole^{-1}$, and in late season PE was 5.4 and 5.7 x 10^{-4} $mgCO_2$ $\mu mole^{-1}$ for Tristis and Eugenei, respectively. The lower values in late season reflect leaf senesence. The similarity in Tristis and Eugenei PE's at both mid- and late season during the establishment year indicate that PE differences alone do not explain observed clonal differences in dry matter production (see Growth Analysis section).

Two-Year-Old Trees.--During the establishment year poplar clones have a simple, single-stemmed crown. However, the complexity of the crown increases in the second growing season with the development of lateral branches. As a result within-tree and between-tree competition for light increases markedly. In the second year, leaf orientation continues to have an important influence on light interception patterns, and single leaf and within-tree photosynthesis. Thus, photosynthetic patterns within the crown continue to mirror those of light interception in both clones. The horizontal leaf display in the upper crown of 2-yr-old Tristis trees resulted in rapid light attentuation within the crown (fig. 5). Light interception was greatest in the large, horizontal current terminal (CT) leaves that are important for height growth and stem wood production (Isebrands 1982). However, the leaves on the upper crown lateral branches of Tristis were still important contributors of photosynthate because they compensated for their low light interception by a large aggregate leaf area (fig. 5). The photosynthetic contribution of the lower crown region was much less than the upper because low light interception was combined with a small aggregate assimilatory area.

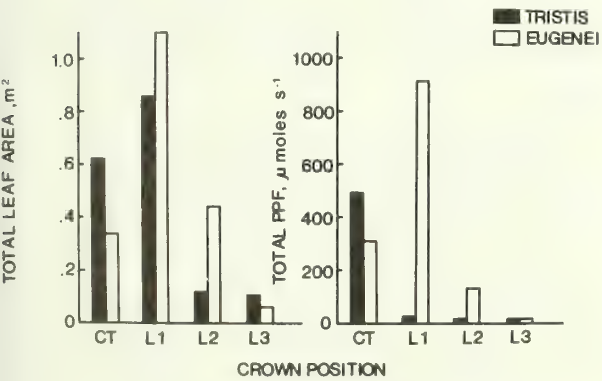

Figure 5.--Total leaf area and total photosynthetic photon flux (PPF) interception of four specific crown regions of individual 2-yr-old P. tristis x balsamifera cv. 'Tristis #1' and P. x euramericana cv. Eugenei trees measured on August 6, 1980. CT = current terminal; L1 = upper lateral branches; L2 = middle lateral branches; and L3 = lower lateral branches.

By contrast, light interception in Eugenei was highest in the upper and middle lateral branches because its vertical leaf display permitted better light penetration to those positions (fig. 5). Leaves on the lower lateral branches received low levels of light and, therefore, had low PgA.

Diurnal patterns of PgL within the crown of 2-yr-old poplars differed with position and with light climate (fig. 6). PgL rates of the CT leaves were the highest in the crown, but PgL rates declined steadily with depth in the crown. Tristis leaves showed a typical bell-shaped curve with peaks at mid-day and that directly reflected changes in photon flux density as the day progressed (fig. 6). However, Eugenei's diurnal pattern (not shown) was more complex because of its vertical leaf display.

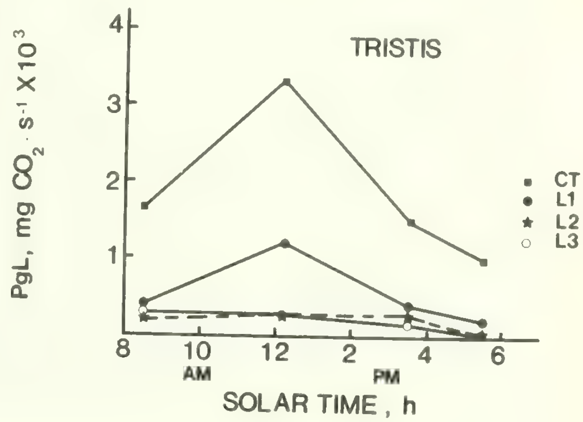

Figure 6.--Diurnal whole-leaf photosynthetic rates (PgL) of four specific crown regions of an individual 2-yr-old P. tristis x balsamifera cv. 'Tristis #1' tree measured on August 12, 1980. CT = current terminal; L1 = fifth lateral branch on height growth increment 1 (HGI 1); L2 = middle lateral branch on HGI 1; L3 = fifth lateral branch from bottom of HGI 1. Each point represents the average PgL of three leaves measured on the same lateral branch.

Three-year-old Trees.--During the third growing season second-order lateral branches develop on each first-order branch in the crown of poplars and add to the complexity of photosynthesis studies. A 3-yr-old poplar crown has four important leaf popluations: (1) the current terminal leaves (i.e. HGI 3), (2) leaves on newly developed first-order lateral branches on HGI 2, (3) leaves on terminal shoots on lateral branches on HGI 1, and (4) leaves on second-order branches arising from the first-order branches on HGI 1.

The general pattern of light interception and PgA that occurs in 2-yr-old trees is also present in 3-yr-old trees. Light interception and PgA rates are highest in the CT (HGI 3) leaves of both Tristis and Eugenei. Leaves on the upper lateral branches are in a more favorable light environment and have higher PgA rates than the middle and lower branches. Young leaves on the current terminals of lower crown (HGI 1) laterals are also capable of high PgA rates if they receive adequate light. A vertical leaf display, such as in Eugenei, allows greater light penetration to the lower laterals resulting in greater PgA rates during midseason compared to a horizontal leaf display, such as in Tristis. However, Tristis retains its lower crown leaves much later into the growing season than Eugenei does. We do not presently know what effect this extended leaf area duration has on total seasonal photosynthate production.

In the third growing season Tristis produces both short shoots (SS) and long shoots (LS) on second-order branches in HGI 1. Photosynthetic rate of LS leaves in mid- to late season is greater than SS leaves because the mean foliage age of the LS is less than the SS; therefore, the LS are more active physiologically than the SS (Nelson and Michael 1982). Both shoot types receive low light levels after midseason and have low PgA rates when located in the lower crown, but the contribution of these shoots may be more important during the early part of the growing season when light levels in the lower crown are greater.

Late-Season Photosynthesis.--Many exotic *Populus* clones grown under SRIC in Michigan and Wisconsin retain green leaves in the autumn for 2 to 6 weeks after native aspen have lost their leaves. For example, some clones retain their leaves until November 1 or after in northern Wisconsin. Leaves on the terminal shoots of clones exhibiting significant green leaf retention have substantial photosynthetic rates during this period (Nelson *et al.* 1982). In two such clones PgA rates ranged from 0.16 to 0.36 mg CO_2 $m^{-2}s^{-1}$ during the late-season period. These values reflect significant carbon fixation when compared to net photosynthetic rates for *Populus* trees growing under favorable conditions (Nelson *et al.* 1982) and suggest that autumnal retention of green leaves may be an important factor contributing to the rapid growth of poplars under SRIC in a cold temperate climate.

PHOTOSYNTHATE DISTRIBUTION

The complex network of biochemical pathways that make up the photosynthetic process converge into the processes of photosynthate production and partitioning (Wallace *et al.* 1976). These processes ultimately determine the components of growth and yield in trees and are amenable to study in the field with ^{14}C-tracer techniques (Isebrands 1982).

Establishment Year.--During the establishment year, growth and development of the young poplar shoot depends upon stored photosynthate until mature leaves develop and begin exporting photosynthate to the shoot. During active shoot elongation and prior to budset, upper mature leaves export photosynthate both acropetally to the newly expanding leaves and shoot and basipetally to the stem and roots (fig. 7A). At budset the direction of photosynthate export makes a dramatically basipetal shift. At this time most of the photosynthate is directed downward to the stem and roots and little if any is exported from one mature leaf to another. Lower mature leaves contribute little photosynthate upward during the establishment year (fig. 7B). After budset, export of photosynthate from lower leaves increases to the roots and decreases to the stem. Although the patterns of export are similar after budset from both upper and lower mature leaves, the total quantity of photosynthate is always greater from the upper leaves[3/] because their photosynthetic capacity is greater (Isebrands 1982).

Poplar clones differ distinctly in the time of budset and leaf fall (i.e., leaf duration). These differences greatly affect the quantity and distribution of photosynthate exported from leaves (fig. 7). For example, Tristis normally sets terminal bud from 4 to 5 weeks before the Euramericana clones. Therefore, the shift to basipetal export of photosynthate occurs much sooner in Tristis. The timing of budset in poplar during the establishment year can also be affected when herbicides are used to control weeds (Akinyemiju *et al.* 1982). Clones susceptible to glyphosate injury often set bud earlier than resistant clones. As a result, photosynthate distribution patterns prematurely shift downward to the stem internodes and roots.

3/ Isebrands, J. G., and N. D. Nelson, unpublished data, 1983.

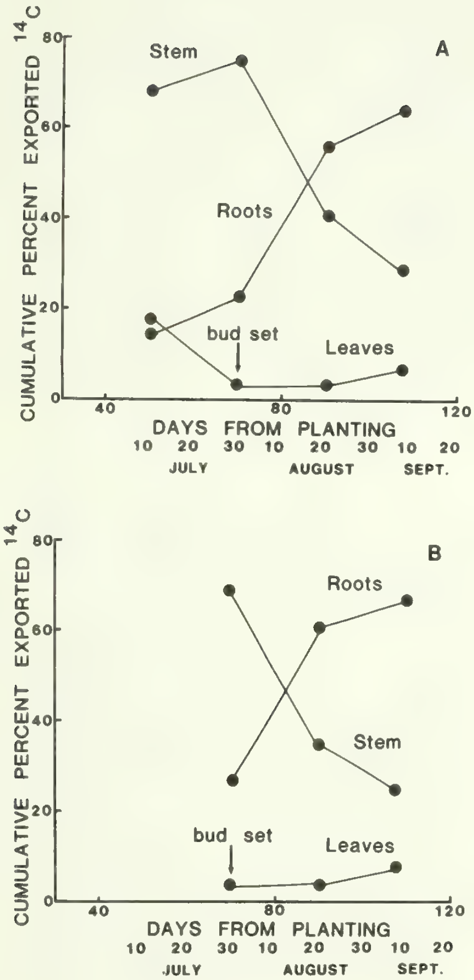

Figure 7.--Cumulative percent of exported ^{14}C from mature leaves of 1-yr-old Populus 'Tristis' shoots grown under SRIC. A. Upper mature leaves treated with ^{14}C. B. Lower mature leaves treated with ^{14}C. Arrows show time at which the current terminal shoot set bud (from Isebrands 1982).

Subsequent Growing Seasons.--During the second and subsequent growing seasons the patterns of photosynthate distribution within the crown are complicated by the addition of lateral branches. The complexity of photosynthate patterns, of course, is related to the intricate photosynthesis patterns discussed earlier. During the second year, as in the first year, shoot growth depends primarily on stored photosynthate until expanding leaves mature. Mature leaves on the current terminal are the most photosynthetically productive leaves in the crown. Carbon fixation declines from the current terminal to the lower lateral branches of the crown (Isebrands 1982).

Photosynthate distribution patterns within second year and older crowns also depends on the various budset and leaf retention times of the current terminal (CT) and lateral shoots (fig. 8). Before CT budset, photosynthate produced by the mature leaves of the CT was exported primarily to the expanding CT leaves above and the elongating CT stem iself (fig. 8A). About 20 percent of the photosynthate produced by the CT leaves was also exported to the stem and roots below. After budset, the quantity exported basipetally to the stem and roots increased, and the quantity exported to the CT itself decreased to about 20 percent. Photosynthate was rarely exported from the CT to the lateral branches.

The patterns of photosynthate distribution from mature leaves on lateral branches were similar regardless of the branch position in the crown (fig. 8B, C, and D). However, the quantity of photosynthate exported and the timing of export from the leaves showed some important differences. Before budset mature leaves of lateral branches exported both acropetally -- to the terminal shoot of the lateral and to the lateral branch itself -- and basipetally to the main stem and roots. Little photosynthate was exported from the lateral branches to the CT shoot or to the other lateral branches. After budset, the quantity of photosynthate exported to the lateral branch itself decreased and the quantity exported to the main stem below and the roots increased. Time of budset differed for various lateral branches in the crown and directly affected photosynthate distribution patterns. For example, budset in the lower and middle lateral branches often occurs 2 to 3 weeks earlier than on the upper lateral branches and 4 to 8 weeks earlier than the CT. Therefore, the basipetal shift of photosynthate export from the lateral branch itself to the main stem and to the roots occurs earlier in the lower portion of the crown than in the upper portion. However, the upper lateral branches generally contribute more photosynthate to the main stem internodes and to the roots than the lower lateral branches (Isebrands 1982).

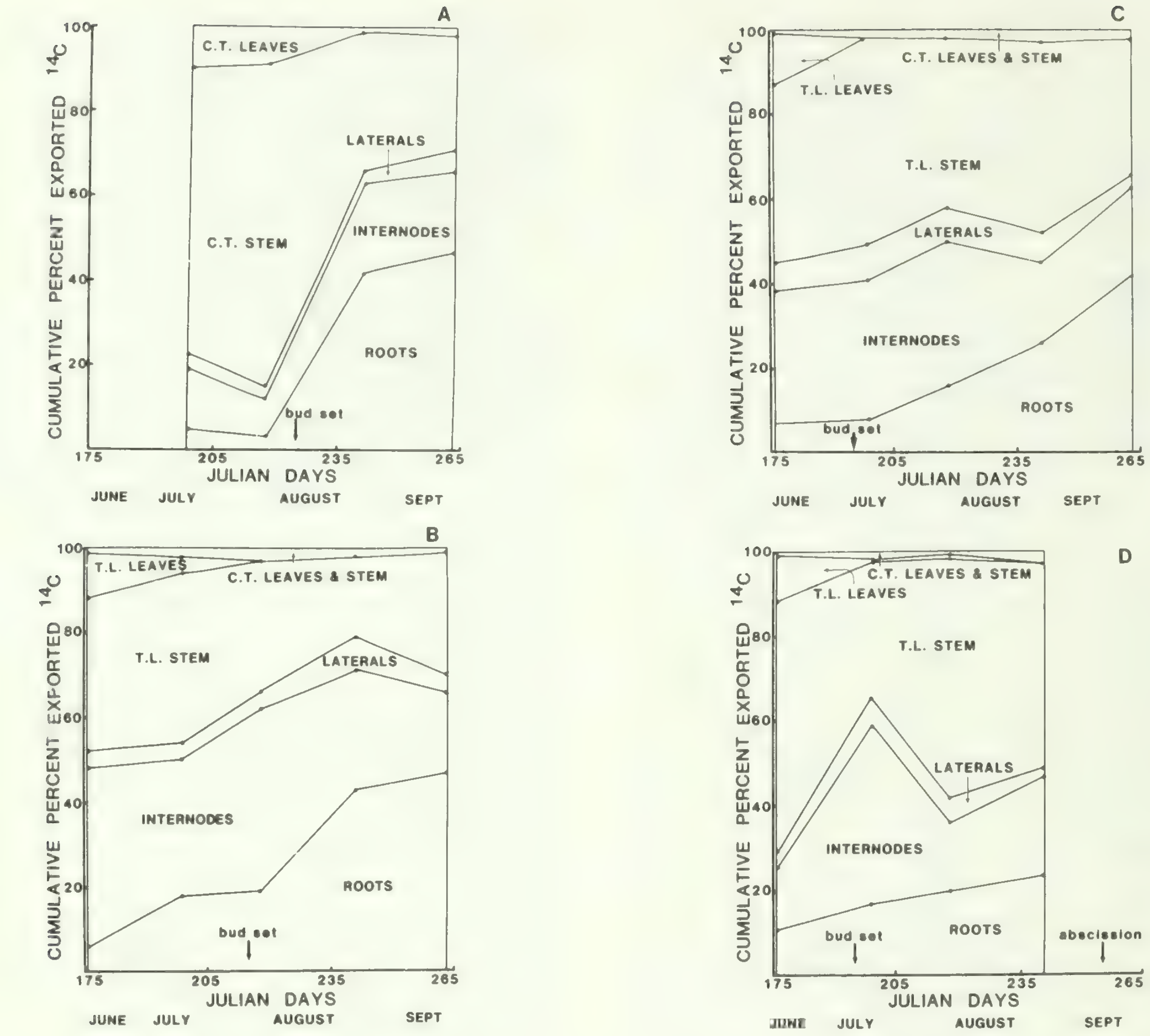

Figure 8.--Cumulative percent of exported ^{14}C from mature leaves at four positions within the crown of 2-yr-old intensively cultured P. 'Tristis" trees treated during the course of the season. Recovery positions include current terminal (CT) leaves, CT stem, treated lateral (TL) leaves, TL stem, lateral branches other than TL, stem internodes of HGI 1, and roots. A. Mature leaves of CT shoot treated with ^{14}C; B. mature leaves of fifth first-order lateral branch from top (L1) of HGI 1 treated with ^{14}C; C. mature leaves of middle first-order branch (L2) on HGI treated with ^{14}C; and D. mature leaves of fifth first-order branch from base (L3) of HGI 1 treated with ^{14}C. Area under the curves estimates the proportion of ^{14}C that would be recovered in a season from a given treatment position. Arrows denote date of budset (A-D) and leaf abscission (D) at each treatment position (from Isebrands 1982).

Although lateral branches in poplar are important sources of photosynthate for wood and root production, little photosynthate from lateral branches is exported to the current terminal shoot. This suggests that lateral branches do not directly contribute to height growth in poplar. Moreover, lateral branches do not export appreciable photosynthate to other lateral branches. Thus, the contributions of lateral branches in poplar are somewhat independent in terms of lateral branch growth. However, the main stem and roots receive localized photosynthate contributions from each of the numerous lateral branches above.

Late Season Photosynthate Distribution.-- Poplars that exhibit substantial autumnal leaf retention and late-season photosynthesis also export considerable photosynthate from those leaves[4/]. For example, mature leaves of the Strathglass poplar clone (NE-1) continued to export photosynthate for at least 2 weeks after the first major frost. The photosynthate produced at this time was exported primarily to the stem and roots for storage and growth. There is also evidence that biochemical products produced by leaves in the late season are involved in the process of dormancy induction in terminal buds. These results illustrate the importance of the autumn season in poplar culture and indicate that clones that retain mature green leaves into the autumn may have an advantage over those that do not.

GROWTH ANALYSIS

Growth analyses are quantitative expressions developed to understand biological productivity on the whole-plant level (Evans 1972, Leopold and Kriedemann 1975). They traditionally have been used to compare cultural treatments, varieties, and progenies, and to interpret factors affecting plant growth (Ledig 1974, Wallace et. al. 1976). Growth analysis techniques are also applicable to the study of photosynthate partitioning in plants (i.e., source-sink relations) (Hesketh and Jones 1980, Warren-Wilson 1981). For example, growth analyses can be used to determine whether a poplar clone achieves high yield through high photosynthetic efficiency or through efficient photosynthate partitioning.

Crop yields can be improved by cultural manipulation and/or selection and breeding. However, these methods are most efficient when the physiological processes controlling yield of the crop are understood. One of the most effective ways to achieve this understanding is through studies that integrate physiological methods with growth analyses on the same plants or in the same experiment. But studies that employ such parallel methodology to clarify the relation between physiological characteristics and yield are rare, particularly in forestry.

Growth analyses were conducted in conjunction with photosynthesis and photosynthate distribution studies of Tristis and Eugenei grown under SRIC during the establishment year. The seasonal patterns of several common growth analysis variables are shown for the two clones in fig.9.

4/ Nelson, N. D., and J. G. Isebrands, unpublished data, 1983.

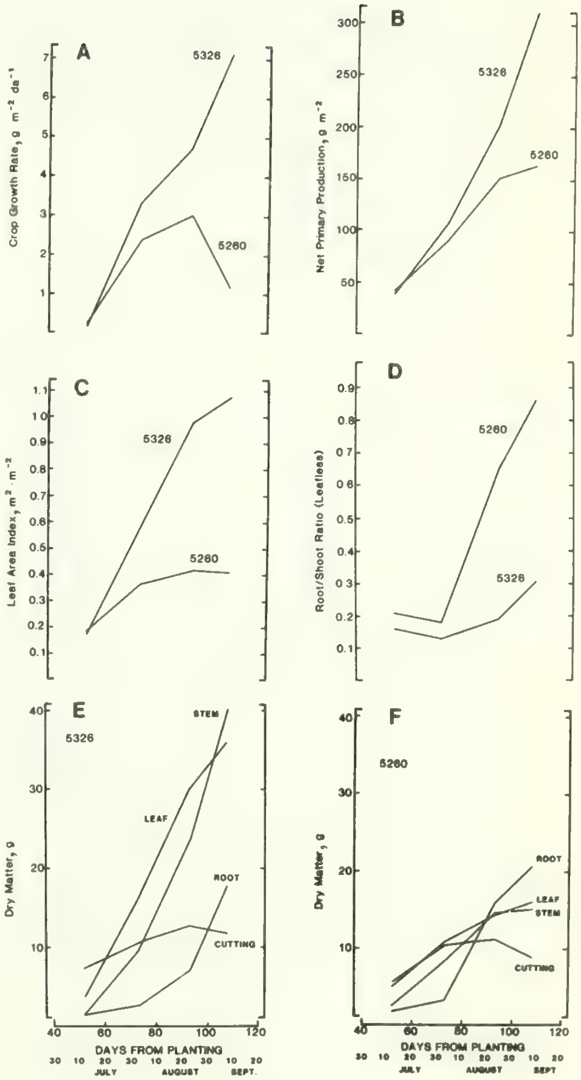

Figure 9.--A comparison during the establishment year of the seasonal patterns of several growth analysis variables for two *Populus* clones grown under SRIC (NC-5326, *P. x euramericana* cv. Eugenei; NC-5260, *P. tristis x P. balsamifera* cv. 'Tristis #1'). A. Crop growth rate (g m^{-2} day $^{-1}$); B. net primary production (g m^{-2}); C. leaf area index ($m^2 \cdot m^{-2}$); D. leafless root/shoot ratio; E. biomass production (g) by component for Eugenei; and F. biomass production (g) by component for Tristis. Total biomass of both above- and below-ground components are included in A and B.

Crop growth rate, the total dry matter accumulated (above and below ground) per unit land area per day, is given in Figure 9A; net primary production, the total dry matter production minus respiration losses is given in Figure 9B. Patterns of leaf area index and root dry matter to shoot dry matter are also shown (fig. 9C and D), as is seasonal accumulation of dry matter by all tree components for Eugenei (fig. 9E) and for Tristis (fig.9F). The growth analysis variables coupled with our physiological data led to a better understanding of the growth patterns of the two clones during the establishment year. Distinct clonal similarities and differences were observed that would not have been apparent from the usual mensurational data such as height, diameter, and volume. For example, growth rate of the two clones was similar early in the season, but Eugenei maintained a high growth rate throughout the season (figs. 9A and 9B). Eugenei's growth rate was large a result of continuous leaf production (figs. 9C and 9E). The large difference in leaf area between the clones apparently was a key factor in their productivity differences. This point is further illustrated by the fact that stem dry matter production closely paralleled leaf dry matter production in both clones (figs. 9E and F). Root-shoot ratios were also distinctly different between the two clones (fig. 9D). As predicted by the photosynthate distribution data, Tristis continued root production after terminal budset and into the autumn (fig. 9D and E). In fact, root growth in Tristis continued after aboveground growth (i.e., height and diameter) had apparently stopped (fig. 9F). At the end of the season Tristis had a root/shoot ratio nearly three times greater than that of Eugenei (fig. 9D). Information on root/shoot ratios during the establishment year may be useful in selecting clones to match the sites. Clearly, both above- and belowground growth data are needed to prevent misinterpretation when comparing clones in establishment studies.

SILVICULTURAL AND GENETIC IMPLICATIONS AND RECOMMENDATIONS

Knowledge gained through physiological investigations such as these can be used to modify silvicultural practices to enhance biomass productivity and in the breeding or selection of new poplar varieties adapted to SRIC systems. The importance of physiological information is evidenced by numerous gains in crop yield made by modern agronomists and horticulturists (Evans 1980). Based on the physiological data accumulated to date, the following practical applications appear evident:

1. Clonal selection and silvicultural practices should emphasize the development of maximum leaf area index for a given spacing throughout the rotation.
2. The major portion of a SRIC poplar tree's leaf area should be in the uppermost crown strata where levels of solar radiation are highest.
3. Clones with erect leaves in the upper crown will probably intercept more light after crown closure than those with horizontal leaves because erect leaves allow for maximum penetration of solar radiation into the lower crown strata.
4. Whereas poplars can usually withstand a single moderate defoliation without appreciable growth losses, massive defoliations by insects or pathogens should be prevented, especially if they are concentrated in the productive upper crown. Defoliation in autumn during the development of vegetative maturity and winter hardiness is particularly harmful.
5. Clones selected for SRIC should attain their maximum rate of leaf area production early in the growing season because such clones generally outgrow those whose maximum rate of leaf area production is not reached until late season.
6. Silvicultural practices and clonal selection should be designed to promote retention of green leaves late in the autumn after bud set, especially in the upper crown. During this time photosynthesis can still take place and much of the photosynthate produced is translocated to the stem and roots. Late-season irrigation and fertilization may promote substantial stem and root growth in clones with late leaf retention.
7. Crown photosynthetic rates are under strong genetic control in poplars and can probably be selected for. However, the cost effectiveness of such a program is currently unknown.
8. Clones with few major lateral branches should be selected for SRIC to promote a high ratio of wood to bark in harvested biomass.
9. Silviculturists and geneticists should emphasize leaf production on the current terminal shoot to increase height growth in SRIC poplars because lateral branches do not contribute photosynthate directly to height growth. However, drastically reducing the leaf area on lateral branches may indirectly affect height

growth through negative effects on carbohydrate reserves and root growth.

0. Narrow-crowned clones with steep branch angles should be used in close-spaced plantations to promote the most efficient use of growing space and maximize interception of solar radiation. Broad-crowned clones with flat branch angles should be used in wide-spaced plantations. The ranking of clones for the most important crown characteristics will not change significantly with spacing.

1. Cultural practices should promote mid-season growth of the terminal leader and uppermost lateral branches because their large, photosynthetically efficient leaves are the major suppliers of photosynthate for stem wood production.

2. A high ratio of long shoots to short shoots in the lower crown of SRIC trees should be promoted for maximum growth.

3. Determinate clones that set bud early in the growing season and thereafter translocate photosynthate to the roots should be planted on harsh, droughty sites where irrigation cannot be supplied. On mesic or irrigated sites where severe moisture deficits are uncommon, indeterminate clones that fully utilize the growing season should be planted.

4. Because the biological optimum rotation for SRIC stand occurs when the relative crown size of trees begins to diminish, stand should not be carried beyond the point where the slope of the linear regression of leaf area per tree (or crown volume) on D^2H declines.

5. To produce the most vigorous coppice stands, SRIC poplar trees should not be harvested immediately after bud set because substantial translocation of photosynthates to the root systems occurs at this time.

These recommendations collectively define our urrent conception of a superior "ideotype" for SRIC poplar tree. The recommendations can be ised by geneticists to select or "design" improved poplar genotypes and by silviculturists o improve their cultural practices.

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RECENT ADVANCES IN RESEARCH OF SOME PEST PROBLEMS

OF HYBRID POPULUS IN MICHIGAN AND WISCONSIN

Lincoln M. Moore and Louis F. Wilson[1]

Abstract.--Hybrid Populus clones were examined for impact from and resistance to attack from several insects and diseases. Cottonwood leaf beetle, poplar-and-willow borer, and Septoria canker were most injurious. The spotted poplar aphid and poplar-gall saperda, even when abundant, caused only minor impact. The tarnished plant bug, a newly identified pest of Populus, injured young trees near agricultural areas. Hybrid clones show a wide range of susceptibility to pests and provide exceptional breeding material for pest-resistant trees.

Hybrid Populus plantings are proving to be particularly vulnerable to insect and disease pests. At least 150 insects and 50 or more diseases are potentially injurious. The insect pests are mostly native ones that feed on aspens and cottonwoods but are equally at home on hybrids grown for intensive culture. For nearly 10 years, the North Central Forest Experiment Station has conducted or supported research on several insects and diseases of hybrid poplars at the Harshaw Farm, Rhinelander, WI; at the Boscobel Nursery and the University of Wisconsin at Madison; and on land owned by the Packaging Corporation of America at Manistee, MI. Results of some of these studies were summarized in an earlier report (Wilson 1979).

Since the last report we have been studying some of the same pests and a few new pests. The most investigated pests include: poplar-and-willow borer (Cryptorhynchus lapathi L.), cottonwood leaf beetle (Chrysomela scripta Fab.), tarnished plant bug (Lygus lineolaris Palisot de Beavois), Septoria leaf spot and canker (Septoria musiva Peck), poplar-gall saperda (Saperda inornata, Say), and spotted poplar aphid (Aphis maculatae Oestlund). We have summarized these studies and a study on simulated insect injury in this report, emphasizing the results during 1979-1982.

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RESEARCH RESULTS

Poplar-and-Willow Borer

The poplar-and-willow borer is the most important boring insect in intensive culture hybrid poplar plantings in the Lake States. It readily attacks young sapling and pole-size trees. Heavy attacks can cause growth loss, stem breakage, tree deformity, and mortality.

The most heavily attacked planting we have studied so far is in a stand of Raverdeau and NE-353 poplars in Benzonia Co., MI, owned by Packaging Corporation of America (PCA). The Raverdeau was established from rooted stock and planted in rows adjacent to NE-353 established from 40 cm cuttings the same year.

Both the Raverdeau and NE-353 clones were attacked by the borer, but the Raverdeau was injured first and more severely. This probably occurred because Raverdeau trees were faster growing and reached a diameter susceptible to attack quicker than NE-353. Morris (1980) and Moore et al. (1982a) found that trees were usually free from attack until they grew to 2.0 cm at the base. All first-year attacks, as a consequence, tended to be within 30 cm of the base. But, as trees aged, borers attacked more often and higher on the tree.

After three growing seasons, nearly half of the Raverdeau and a quarter of the NE-353 trees were attacked. By then only 10 out of 1,400 trees had died or broken over. Data from other locations, however, indicate that more damage is

ossible because borer-infested trees are articularly susceptible to breakage from wind or ce (Morris 1980).

We examined poplar-and-willow borer attacks n a stand at three levels of Populus biomass ensities at Rhinelander, WI, in 1981. The clone ensities were at 5,000, 10,000, and 15,000 T/ha. oplar-and-willow borer was counted on three P. x uramericana clones: NC 5323, 'Canada Blanc'; C-5326, 'Eugenei'; and NC-5377, 'Wisconsin #5' t these three densities. The preliminary data table 1) were too variable to indicate whether r not density is related to borer attack.

able 1.--Poplar-and-willow borer attacks on three P. x euramericana clones at three biomass densities

lone	Mean attacks at densities (T/ha) of: 5,000	10,000	15,000	All
Canada Blanc'	7.2	1.8	15.6	8.2
Eugenii'	4.8	2.8	4.8	4.1
Wisconsin #5'	9.0	3.6	7.0	6.5
Mean Total	7.0	2.7	9.1	6.3

Cottonwood Leaf Beetle

In recent years, the cottonwood leaf beetle as become the number one defoliator in certain isconsin and Minnesota plantings of hybrid opulus. Hybrid selections of 12 standard clones nd tissue-cultured subclones of P. x uramericana grown at the Boscobel Nursery in isconsin gave us an opportunity to study the nsect in greater detail.

Cooperators at the University of Wisconsin et out to study the beetle's biology and cology, to determine its host preference for eeding, and to study the subsequent utilization f Populus tissues as a nutrient source for its rowth and development.

The cottonwood leaf beetle (CLB) is a highly rolific insect--females produce an average of 10 eggs (Burkot and Benjamin 1979). In southern isconsin four generations occurred between May nd September, each generation appearing at about 0-day intervals. After the last generation the dults overwintered in the leaves and debris eneath the host trees.

Larvae, soon after hatching, fed gregariously nd skeletonized the foliage. As they aged, they pread out and devoured entire leaves. When food ecame scarce, the beetles consumed young bark of hoots on the tree tops. Adult beetles also fed n the foliage, adding to the injury.

Life-table studies suggest that predators and parasites kill many CLB's but not enough to keep the population below economic thresholds. The most significant biological control agents found were: Coleomegilla maculata DeGeer, which consumed 25 percent of the eggs; and Shizonatus latus Walker, a pteromolid parasite which destroyed 26 percent of the pupae. The pentatomids Podisus maculiventris Say and Perillus bioculatus Fab., and lacewing and syrphid flies accounted for a small percentage of the young-larval mortality. Few natural enemies attacked the larvae mainly because of the defensive secretion they emit when disturbed or attacked.

Starvation was another main cause of death; four generations of beetles quickly over-ran their hosts and rapidly defoliated them. Population increases showed a potential in excess of 25, 18, and 8 times for the first three generations respectively, which produced millions of beetles in the nursery each season.

Taxonomically the genus Populus is subdivided into five sections. The three major ones are Leuce, Aigeiros, and Tacamahaca. In host preference tests between clones of these three sections, CLB adults would not feed on hybrid clones from the Leuce section (table 2).

Table 2.--Populus clones and CLB feeding preference

Clone	Defoliation Level[1/]	Sectional Composition[2/]
	(percent)	
'Crandon'	0	100% Leuce
NE-1	22	50% A., 50% T.
NE-299	33	50% A., 50% T.
DN-21	41	100% Aigeiros
NC-5260	47	100% Tacamahaca
NE-298	49	50% A., 50% T.
NE-372	51	25% A., 75% T.
NE-387	52	25% A. 75% T.
'Wisconsin #5'	65	100% Aigeiros
NE-252	66	50% A., 50% T.
NE-386	68	25% A., 75% T.
NE-375	78	100% Aigeiros

1/ Level of defoliation reported by Caldbeck et al. (1978).

2/ A. = Aigeiros; T. = Tacamahaca

We expected the beetle to reject the Leuce foliage because the aspens and white poplars in this section are not normally hosts of the CLB

(Harrell *et al*. 1981). Beetles occasionally nibble these hosts but barely injures them because the foliage was generally unsuitable for their development (Caldbeck *et al*. 1978, Wilson 1979).

The adults showed an intermediate preference for *Aigeiros* clones and a high preference for all clones with *Tacamahaca* parentage. Leaf extractions and bioassays indicated that one or more sugars may be responsible for these preferences. Such differences suggest that increasing the *Aigeiros* component in future hybrids might make them more resistant to the CLB.

By examining CLB's when exposed to a single tissue-cultured clone (*P. x euramericana* 'Wisconsin #5'), cooperators found that moisture content and foliage affected the beetles' development and behavior (Harrell *et al*. 1982). Larvae fed equally on all leaves with water contents greater than 73 percent but did not feed on leaves with less than 70-percent water. In the latter case, the larvae fed on the shoots instead of the leaves. Adults, however, prefered the more succulent, high-water content leaves in the upper crown (table 3).

Table 3.--Adult cottonwood leaf beetle feeding preference with respect to *P. x euramericana* leaves of different maturity

Leaf position on stem	Mean leaf water content	Mean leaf consumption
	(percent)	(mm^2 $\pm$ S.E.)
1 (youngest)	80.9	57.1 $\pm$ 10.33
2	80.2	32.7 $\pm$ 11.80
3	76.8	2.1 $\pm$ 1.01
4 (oldest)	75.2	0.6 $\pm$ 0.33

Larvae were affected by foliage. They developed in an average of 13.5 days on immature foliage and in 14.6 days on mature foliage. Of even greater significance was insect size relative to foliage maturity. Larvae reared on immature foliage yielded prepupae weighing 42.3 mg in contrast to the prepupae weighing 33.5 mg from those reared on mature foliage.

These results suggest that leaf water content or some other leaf constituent that varies with water content has an important influence on the feeding of CLB's and the damage these insects cause. Other plant factors that may be important in reducing CLB feeding and development on the more mature leaves include a lower nitrogen content and higher amounts of fiber and tannins. Additional studies are needed to determine the importance of each of these plant factors so that the information can be utilized in developing resistant poplar clones.

Tarnished Plant Bug

In 1978 an unknown agent began injuring young hybrid *Populus* trees planted on the Harshaw Forestry Research Farm near Rhinelander, WI. Each summer thereafter, lesions developed on the stems and occasionally on short branches, growing tips, and leaf petioles of certain clones of newly planted and 1- and 2-year old *Populus* grown from cuttings. The stem lesions occurred in the middle or upper portion of young trees; the injured areas sometimes calloused over but frequently stems were girdled or broken above the injury. The injured area was technically a split-stem lesion and when fully formed consisted of an irregular elongate split with a swollen flared area of necrotic bark and xylem tissues around the stem (fig. 1). Mature lesions ranged from less than 0.5 cm to 5 cm long.

Figure 1.--Split-stem lesion on *Populus* caused by tarnished plant bug

Initial dissections of lesions for insects and isolations for pathogens provided no clue to the cause of the injury (Sapio *et al*. 1982). A possible insect and disease association, however, was indicated after the application of malathion,

hich eliminated most insects at the spray site. ew lesions continued to form in an unsprayed rea after the treatment but only a few formed in he treated area. In 1981 we set out to etermine the causal agent of the lesion, ncidence of injury among various Populus clones, nd the best ways to prevent it.

Many field and greenhouse tests ultimately dentified the causal agent as the tarnished lant bug, normally a destructive pest of gricultural and fruit crops such as alfalfa, otton, beans, apple, and peach. Though many ygus bugs closely related to the tarnished plant ug (TPB) transmit pathogenic fungi to plants, he TPB did not appear to induce the lesions by ectoring pathogens. Instead, it may have caused esions through enzymatic activity from its aliva.

TPB's fed on and caused lesions on various lones of hybrid poplar as well as quaking and ig tooth aspen. An examination of 20 clones at he Harshaw Farm revealed that NE-298, NE-386, E-387, and NC-9921 appeared to be consistently he most susceptible. Clones NE-299 and NC-9922 ppeared totally resistant in a clonal trial, but ere moderately lesioned in other locations. We uspect this may have been because the TPB referred these clones over less desirable ones r because it lacked other suitable food sources earby. All clones are probably somewhat usceptible to TPB injury when food choice is imited. For instance, clone NE-375 which ppeared highly resistant, developed lesions when aged with TPB's. In fact, it developed more esions than susceptible clone NC-9922.

Field tests further suggested that Populus esistance is tempered somewhat by the trees' roximity to preferred food sources such as orseweed and fleabane--two weeds common at arshaw Farm. Also, when white dutch clover was sed as a cover crop, it seemed to attract the PB's and prevent injury to Populus. White dutch lover is one of the TPB's favorite hosts and pparently highly preferred over Populus.

During the first two growing seasons after lanting, Populus hybrids showed the highest risk or the TPB lesion. TPB's rarely fly more than m above the ground, so the succculent tissue of he mainstem of Populus is usually well out of each after the second growing season. The TPB ay also feed on the lower twigs but its impact s inconsequential to Populus growth and biomass roduction.

Cover cropping may minimize TPB injury if roperly used or integrated with pesticides. tudies on the management of horseweed, white utch clover, alfalfa, and other associated reatments are still needed before conclusions an be drawn. Horseweed is somewhat resistant to glyphosate herbicide and its presence seems to be beneficial in lowering incidence of lesions. Perhaps some flowering weeds should be maintained near Populus plantings to entice TPB's away from the trees. Such weeds also encourage parasites that are drawn to the pollen to feed.

The TPB can be suppressed by one or more applications of suitable insecticides. Ultra-low volume malathion has been successful at 9.7 oz. actual insecticide per acre when used in alfalfa fields. It appears to be useful only for short-term suppressions, however, because emigrating adults quickly repopulate an area. Also, there are at least three generations of the TPB in Wisconsin, which further complicate matters.

All in all, perhaps an early season spray integrated with an appropriate weed-management program might successfully control the tarnished plant bug in young Populus stands.

Septoria Leaf Spot and Canker

Septoria is a serious disease on the leaves and stems of hybrid poplars of all ages. This fungus causes small necrotic spots on the leaves; heavy infection usually causes premature leaf drop. Cankers form on the mainstem and branches. Coalescent cankers reduce growth, cause stem breakage, and kill trees. Spores of this disease are carried by wind and rainsplash to leaves, stems, and branches where infection occurs.

In 1979 some nursery stock and a Populus plantation adjacent to the PCA nursery were infected by Septoria. Becoming heavily cankered, the plantation was cut in 1980 for firewood and the stumps were allowed to resprout. In 1981, these sprouts were also cankered and additional nursery stock was infected.

To study Septoria, we set out to determine the severity and site of Septoria infection of first-year coppice and to determine the most susceptible clones in the nursery stool beds.

After coppicing, there were an average of 34 sprouts per stump (range 2-84), and 52 percent of these sprouts were infected in the fall of 1981. All but one of the 75 stumps examined had at least one cankered sprout. Septoria canker was more prevalent on lower stems at leaf petioles and buds as compared to elsewhere on the stems. Densely spaced sprouts encouraged Septoria infection by trapping infected leaves and retaining a moist micro-environment ideal for infection. Infected leaf debris around the stumps also contributed to pathogen retention, spread, and disease severity (Moore et al. 1982b). The severe Septoria infection in the plantation was the result of planting highly susceptible clones.

Nursery stool beds may be even more vulnerable to Septoria than plantations because they are more closely spaced and thus retain higher moisture. Overhead irrigation probably further increases infection. Nearly two-fifths of the clones in the nursery were heavily infected with Septoria. All the P. maximowiczii crosses were heavily infected. This group has been highly susceptible in inoculation tests (Waterman 1954), and cankers also have been found on this species in the eastern U.S. As the male parent, P. trichocarpa appeared in 11 of the 19 highly susceptible crosses at PCA and in none of the resistant clones, indicating that it may contribute to clonal vulnerability to Septoria. P. trichocarpa crosses (as the male parent) have been rated more susceptible to Septoria than P. deltoides (as the female parent) (Waterman 1954). Six of our infected P. deltoides crosses were ones with P. trichocarpa and were among the heaviest cankered.

This study indicates that Septoria canker and leaf spot is certainly one of the most damaging diseases of hybrid poplars in Michigan and, unless managed, can limit the usefulness of susceptible clones. Nursery stock and plantation coppice are infected by spores from infected leaf debris in early spring. Removing this debris is one way to control Septoria. However, local screening of clones for resistance and planting these resistant clones is the most promising long term control strategy in areas where Septoria is known to be a problem. Until this screening is complete, land managers should be aware of the potential hazard from Septoria, if highly susceptible clones are planted. Hybrid poplars with P. trichocarpa, P. laurifolia, or P. maximowiczii as one of the parents were the most susceptible to Septoria and probably should not be planted where this fungus is known to be present.

Poplar-gall Saperda

The poplar-gall saperda attacks the stems and branches of natural and hybrid Populus. Larval feeding forms a swelling that weakens the stems and branches, sometimes causing them to break or die.

During our investigations in PCA plantings in Michigan, we had an opportunity to study the incidence of saperda attacks and the insect's impact in an outplanting of 5-foot tall Populus whips of mixed clones planted in the spring of 1979. The planting was set out in a clearing surrounded by saperda-infested aspens that apparently permitted rapid infestation of the whips.

In the first season of attack, more than 60 percent of the whips were galled by the beetle. Average attack was nearly 2 galls per tree (range 0-12 galls/tree). By the end of the season, 2.6 percent trees died from galls near the base of the trees. Another 7.5 percent were top-killed from galls higher on the stem. Attacks the second year gave the tree another two galls per tree, but nearly 30 percent were on the branches. By the end of the second season, mortality rose by 0.2 percent to 2.8 percent and top-kill increased by 1.5 percent to 9.0 percent. Height differences between galled and ungalled trees were statistically insignificant after the second year.

These data suggest that the poplar-gall saperda does not appear to be a threat to young trees up to the attack level of an average of four galls per tree. Mortality of 2.8 percent after 2 years is not much more than might be expected from most other causes and certainly only a minor concern for biomass production. Almost no additional trees died after the second year mainly because old-galled areas become overgrown by the tree. This also minimized breakage as the tree is strengthened by the new growth. Most top-killed trees resprouted new shoots and quickly regained most of the lost height the following season, suggesting that breakage has little impact on biomass production. So far, this insect has not proved to be a destructive pest and further research is needed with many Populus clones under variable growing conditions before its real impact can be determined.

Spotted Poplar Aphid

The spotted poplar aphid feeds on the terminal shoots of various species of Populus. Clustering in tightly nested colonies, these aphids en masse often cover the entire growing tip and first two or three ranks of leaves during mid and late summer.

This insect has been a perennial pest in the PCA nursery in recent years. We rated all the clones in the nursery according to their susceptibility to this aphid and examined its impact on growth. We also tested two insecticides for controlling the aphid.

Clones of Populus x jackii were the most susceptible to the aphid, having the most numerous attacks and largest aphid colonies. The five next most susceptible clones were NE-19, NE-41, NE-209, NE-298, and NE-360. Resistant clones were NE-19, D-38, I-4551, NE-375, NE-224, and NE-238. None was attacked in the nursery. All other clones were attacked by at least a few colonies and varied from a trace to a moderate infestation. When heavily infested stool-bed suckers were compared to non-infested ones within clones of P. x jackii, we found no significant growth differences at the end of the growing season.

Two insecticidal soaps were tested on aphid colonies on four Populus clones at recommended full strength (1.0%) and half-strength (0.5%) dosages. The chemicals tested were Safer insecticidal soap concentrate containing 50.5 percent potassium salts of fatty acids, and a 10 percent mono-L-pesticide developed in the Department of Biomechanics at Michigan State University. The treatments were tested at the PCA nursery and at Morin's Nursery at Manistee, MI.

Both insecticides and dosages controlled the aphids about equally on three of the clones--DN-22, DN-28, and Raverdeau (table 4). Control was slightly less effective on DN-55 colonies.

Table 4.--Control of spotted poplar aphid on cottonwood clones with insecticidal soaps

Populus clone	Insecticide	Dosage	Aphids controlled
		(percent)	(percent)
DN-22	Safer	0.5	88
	Safer	1.0	91
	MSU	0.5	89
	MSU	1.0	94
DN-55	Safer	0.5	76
	Safer	1.0	77
	MSU	0.5	86
	MSU	1.0	84
DN-28	MSU	0.5	96
	MSU	1.0	91
Raverdeau	MSU	0.5	93
	MSU	1.0	88

We concluded from these tests that the insecticidal soaps gave sufficient control to disrupt the colonies for the remainder of the season. However, we would not recommend MSU's formula because it caused some burning of foliage when applied on sunny days, although it controlled adequately.

Insect Damage Simulation

Cooperators at Michigan State University completed tests on the effects of simulated insect damage of hybrid Populus in a study planting at Rhinelander, WI (Bassman et al. 1982). Insect defoliation and girdling/boring was simulated to assess potential growth impact under nursery conditions. Partial defoliation in several patterns was tested both early and late in the growing season. Clones tested were: NE-298 (P. nigra var. betulifolia x P. trichocarpa); NC-5260 (P. tristis x P. balsamifera) and NC-5351 (Populus sp.).

Trees that had defoliation levels of 40 percent were identical in height growth to non-defoliated trees showing that moderate defoliation is not cause for concern even in such young trees. Further, the young trees appeared to sustain 2 years of 40-percent defoliation without significant growth loss as long as favorable growing conditions were maintained. Defoliation levels of 75 to 80 percent, however, consistently produced significant height growth reductions on the order of 20 percent. Complete defoliation was not tested because normal practice would be to apply insecticides if defoliation appeared likely to become that severe.

Timing of defoliation in the growing season did not seem to be particularly important for growth of trees defoliated 40 percent. Late-season defoliation, however, can be more deleterious than earlier defoliations that allow time for subsequent recovery before bud set in the fall. Location of defoliation on the tree was insignificant to growth loss, indicating that an insect preferring new foliage would do no more damage than one preferring old foliage.

Effects of basal injury by girdling and boring followed a pattern somewhat similar to that of defoliation. Damage had to be severe enough to weaken the stem almost to the point of collapse before there was significant growth loss. Basal injuries healed rapidly in vigorous stock and caused no lasting effects. We should point out that such wounds, however, may be infection sites for pathogens that could kill the trees.

We should also note that these tests did not encompass direct damage to leaders. Several modes of insect attack result in leader damage, and these are difficult to simulate mechanically. In particular, the feeding of aphids does not lend itself to investigation by simulation. Experiments with caged insects are needed in this regard.

DISCUSSION

Since research has begun on Populus pests in the North Central Region, the cottonwood leaf beetle has been the predominant defoliator with the greatest impact. Because we now know a great deal about the behavior of this insect as well as much about the physical factors of the host trees, the next appropriate step for research is to examine the chemical cues in Populus that repel or attract and safeguard the insect once on the tree. Research will need to interrelate the physical and chemical factors in order to understand host resistence mechanisms. For instance, we will need to learn what concentrations of nitrogen and other nutritional

components of the foliage relate to the feeding behavior and growth of the cottonwood leaf beetle. Also, allelopathic chemicals in the host that are certain to provide further mechanisms of host resistence. Populus is ideal for such research because it has a wide range of resistance and susceptibility to this beetle. Because of this and because the cottonwood leaf beetle is the most important defoliator in the region, it might be considered first in pest-resistent breeding programs.

Two insects we investigated--the spotted poplar aphid and the poplar-gall saperda--which are potentially destructive pests of nursery stock and 2- to 3-year old planted trees, caused only minor impact, even when abundant. This suggests that these two insects have been overrated as pests of poplars. For instance, aphid colonies exceeding 800 insects only slightly deformed a few leaves on the tips of some sprouts. Growth differences were insignificant as compared to unattacked sprouts. Similarly, saperda caused a few trees to break over or die-back, but most of those trees resprouted the following year and nearly caught up in height within 2 years. The saperda may have more injury potential under unusual circumstances. High winds or ice storms, for example, might precipitate greater stem breakage. Two or 3 years after outplanting, however, most poplars in our study were nearly immune to stem-injury from saperda.

Septoria canker is the worst disease organism investigated on Populus in both the nursery and plantations. Because many otherwise favorable clones are attacked, this disease will require further and immediate research for its prevention and control.

The poplar-and-willow borer is potentially the worst boring insect so far encountered in the region mainly because it can destroy sapling-size trees. Research will need to continue on this pest in the next few years in order to learn the full extent of its impact. Cultural practices, such as fertilization and thinning, should be tested further to learn how they modify the weevil's behavior.

Cultural practices should also be researched on the tarnished plant bug and Septoria canker, especially where 1-to 2-year old trees need protection. Cover cropping, the role of weeds, and variables related to moisture also need to be studied.

All these studies suggest further that we need to change how we perceive control of some Populus pests--particularly the insects. The poplar-gall saperda and the spotted poplar aphid are two good examples in which damage potential appears to be high but control may rarely be needed. The damage simulation tests further show that Populus can tolerate much defoliation and boring injury before control treatments are needed. Defoliation at 50- to 60-percent levels for 2 or more consecutive years seems to be nearly inconsequential to growth and biomass production. Similarly, borers need to literally riddle a stem before economic thresholds are reached and control is needed.

In conclusion, it appears that if proper pest-preventive measures are taken before and during the growing of Populus hybrids, reasonably resistant trees are planted, and good cultural treatments are adhered to, many Populus pests should be kept at sufficiently low levels to maintain full biomass production.

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DISEASES OF INTENSIVELY CULTURED HYBRID POPLARS:

A SUMMARY OF RECENT RESEARCH IN THE NORTH CENTRAL REGION

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Abstract.—Several potentially damaging diseases of hybrid poplars have been identified in the north-central United States. Among the most serious are leaf and stem diseases caused by *Melampsora*, *Marssonina*, and *Septoria*. Short-term chemical controls are of limited usefulness. The most practical control strategy appears to be the use of resistant clones obtained through local screening, combined with various cultural measures, and integrated into overall management plans.

Introduction

The increasing demand for economical wood fiber and energy, together with the competition for land has created an interest in establishing short-rotation, intensive tree culture systems to maximize biomass yield per unit area. Recent research in the north-central United States has concentrated on the use of hybrid *Populus* and the application of agronomic practices to establish and manage high yielding plantations on short rotations to provide raw material for industrial and energy uses. *Populus* appears well-suited for management under such a system because of its rapid growth, genetic diversity, ease of vegetative propagation, and coppice regeneration. However, past experience with growing hybrid poplars in Europe, Canada, and the southern and northeastern United States indicates that pathogens and insect pests can severely limit the productivity or lower the quality of affected trees. Because plantations are costly to establish and maintain, they must be protected from serious damaging agents. This paper will summarize the major findings of recent research into the potential impact and control of diseases of intensively cultured hybrid poplars in the north-central region.

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Disease Detection and Pathogen Identification

Foliage Diseases

Poplar leaf rust, caused by *Melampsora medusae*, was the first disease recognized as having the potential to severely reduce biomass yields (Schipper and Dawson 1974). Rust reduced wood volume of susceptible clones up to 42 percent in research plots in Wisconsin, Minnesota, and Iowa (Widin and Schipper 1981). Impact from rust is most severe on poplars planted within the natural range of *Larix*, its alternate host, where poplars are infected early in the growing season. Other virulent races of *M. medusae* may also be present (Singh and Heather 1982). In addition, other rust species could infect previously resistant poplars. Fungicides will protect trees, but screening and selecting rust-resistant clones is the best control strategy.

Insects and pathogens affecting 32 clones of hybrid poplars were detected and identified in 13 small plantations planted throughout the north-central region in 1976 and 1977 (Ostry 1979). Data were collected on the prevalence and severity of damaging agents several times during each growing season through 1982.

Several foliage diseases, some of them potentially serious, were identified. Poplar leaf rust was of lesser importance in the southern plantations than in the north where premature defoliation of susceptible clones was common. *Phyllosticta* leaf spot, a

disease of minor importance except on young trees, was most severe in southern Illinois and rarely found north of Iowa. Septotinia podophyllina was found only in the northern region. It causes a leaf spot in the lower crown late in the season but may be of periodic importance on young trees. Venturia macularis causes a leaf and shoot blight that kills terminal portions of trees, reduces growth, and deforms trees. It was most severe on young trees in the northern region.

Marssonina brunnea causes a leaf spot and lesions on the current year's stem growth and was present throughout the region. Highly susceptible P. X euramericana clones were prematurely defoliated by Marssonina, resulting in reduced growth. Other reductions in root growth and depletion of root starches may predispose defoliated trees to environmental stresses and other diseases (Bassman and Dickmann 1982).

Marssonina was of minor importance until it reached epidemic proportions at Rhinelander, Wisconsin, in 1978 and at Rosemount, Minnesota, in 1980, illustrating how disease impact can change in poplars when inoculum levels increase and conditions for spore dispersal and infection of susceptible clones exist. Marssonina infection decreased in 1981 at Rosemount largely because most of the susceptible trees were more than 8 m tall and their lower live crowns were 3-4 m above the ground. Moisture dries more quickly on leaves at this height, reducing conditions favorable for infection. From observations in our research plots, it appears that Marssonina is most damaging on young trees grown at close spacings.

To better understand the life history of Marssonina and other pathogens, we placed spore traps in and around poplar plantations in Michigan, Wisconsin, Minnesota, and Iowa from 1980-1982. Weather data also were collected. Disease symptoms and tree phenology were recorded throughout the growing season. We found that Marssonina conidia or ascospores of its perfect state (Drepanopeziza) are liberated throughout the entire season (Figure 1).

In 1977 leaf spot caused by Septoria musiva was found on poplars in all plantations except Rhinelander, where it was not found until 1980. It was, however, present on native P. balsamifera in this area. Premature defoliation of trees of several highly susceptible clones reduced their growth and predisposed them to other pathogens and environmental stresses, resulting in extensive dieback. Infection of poplar leaves in spring results from ascospores of Mycospharella populorum, the perfect state of S. musiva, being liberated from infected leaf debris on the ground (Figure 1).

Stem diseases

Deer browsed heavily on trees in northern Minnesota and Michigan. Diseases such as Venturia and heavy weed competition prevented many trees from outgrowing the reach of deer and Cytospora dieback was common on these trees. Vigorously growing trees in larger plantations could outgrow the deer hazard.

Branch and stem diseases other than Cytospora were rare on trees until after 1978, when cankers caused by Dothichiza populea and S. musiva became important. Cankers caused by Dothichiza were most severe at Rosemount. Stem breakage at these cankers began in 1981. Susceptibility varied by clone and species perhaps because of the difference in clonal rooting depth (Haywood and McNabb 1979). The perfect state of Dothichiza, Cryptodiaporthe populea, was present on infected trees--the first report of the perfect state in the United States. The ascospores of this perfect state may be important in the spread of the fungus within plantations. Field testing to select trees for drought resistance may be warranted to reduce the incidence of this disease as well as Cytospora and Phomopsis dieback. To guard against stress related diseases, clones should be matched to sites they will occupy.

Septoria cankers were first recorded in 1978 near Ames, Iowa, and at Rosemount. Poplar stems inoculated in a greenhouse with isolates of Septoria obtained from leaf spots resulted in the typical sunken cankers observed in the field. Canker severity remained high at these two locations, and stem breakage began in 1979 as a result of multiple cankers on stems of highly susceptible clones. Many of these trees have resprouted and died back repeatedly from subsequent cankering. In contrast, trees of these same clones growing at Rhinelander remained healthy until late summer, 1981, when Septoria canker was first observed. Cultivation was more frequent and thorough at Rhinelander than at other study sites and may have been a factor in reducing overwintering inoculum. Cultivation was discontinued when tree size made it difficult to operate machinery in the plantings and spore trapping confirmed an increase in inoculum within plantings.

Susceptibility to Septoria varies, necessitating local screening of poplar clones before large acreages are planted. In

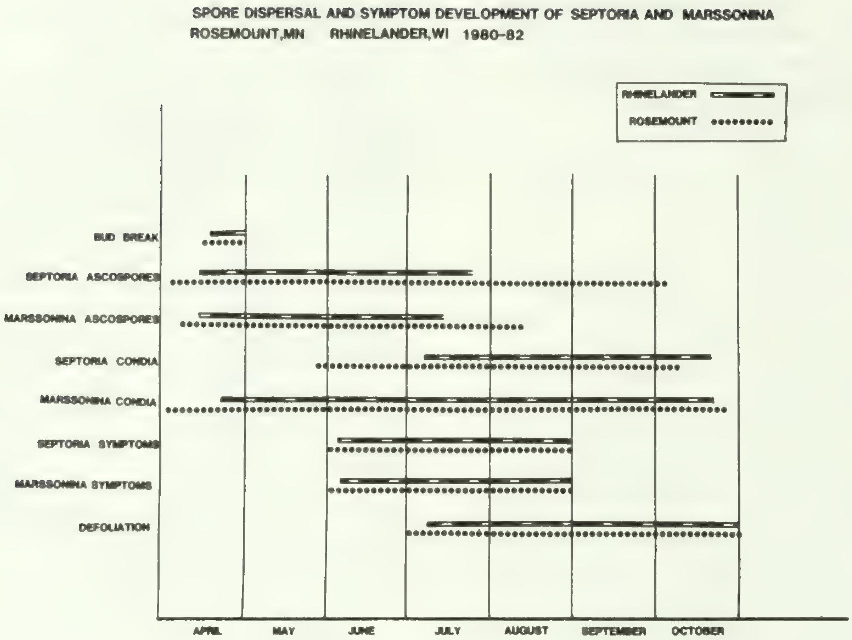

Figure 1.--Spore dispersal and symptom development of Septoria and Marssonina at Rosemount, Minnesota and Rhinelander, Wisconsin 1980 - 1982.

one area where this was not done, trees of many susceptible clones were propagated in a nursery and outplanted. Heavy cankering by Septoria resulted in early failure of several plantations and many clones were removed from the nursery (Moore et al. 1982).

Root Diseases

Armillariella mellea causes a root and butt rot usually, but not always, of weakened trees. A late spring frost in 1981 at Rhinelander killed flushed leaves and cambium of trees of several clones that were also highly susceptible to foliage disease. A. mellea was found on these trees and together with other pathogens resulted in the decline and eventual death of the trees. Root rots may become increasingly important in older plantations and stands of coppice regeneration.

Screening for Resistance

Three plantations, each containing more than 500 species and clones of poplars were planted in 1978 to screen many genotypes for field resistance to Melampsora, Marssonina, and Septoria. Plantations were located at Rosemount, Rhinelander, and near Ames. Resistance to the diseases caused by the major pathogens varied widely. As in the previously described plantings, identical clones planted at Rosemount and near Ames were heavily infected by Septoria, but those clones were free from cankers until 1981 at Rhinelander. Cultivation again was much more thorough at Rhinelander than at the other sites and is thought to be responsible for less Septoria infection. Melampsora defoliated highly susceptible clones at Rhinelander more than a month before symptoms appeared on the same clones at Ames. Tree growth and winter hardiness also varied by clone and location. At this time, 104 of the clones planted are disease resistant at all 3 locations. A total of 130 clones are too susceptible to Septoria canker to be recommended for planting at any of the locations (Ostry, unpublished data).

Results of this screening study revealed the importance of field testing clones for disease resistance. Repeated observations of disease development over the growing season detected clones that became heavily infected with rust or Marssonina late in the season in contrast to highly susceptible clones that became infected early in the season. Some clones moderately susceptible to Melampsora at Rhinelander could be safely planted near Ames. Genotype-environmental interactions and variation among clones in susceptibility to diseases underscore the importance of "tailoring" planting stock for each site and area within the region. In the future it may be desirable to screen clones at the spacing at which they will be grown, to judge their relative competitiveness and disease susceptibility at that spacing (McNabb et al. 1982a).

Impact of Septoria Canker

Impact of Septoria canker on a mixed hybrid poplar plantation planted at 10,000 trees/ha was studied in central Iowa from 1977 through 1981. Biomass production of the first rotation was determined from a cut made in the winter, 1979-80. The mixture included clones with high and moderate susceptibilty as well as resistant hybrids of similar biomass production potentials (Table 1). The resistant hybrid produced three times more biomass by weight than did the highly susceptible clone. In addition, 30 percent of the resulting stumps failed to resprout in the highly susceptible hybrid compared to only 3 percent failure for each of the other 3 clones (McNabb et al. 1982b). In pulping studies, cankered wood, either as the sole source or in mixtures with healthy wood where it exceeded 25 percent by dry weight, proved unsatisfactory for pulp fiber used in kraft paper production (Holt et al. 1981). Cankered wood had higher lignin and extractive content than uncankered wood. Paper produced from this pulp stretched significantly further, and it had lower tensile and bursting strength, burst factor, and breaking length.

Chemical and Cultural Control Trials

Short-term chemical disease control is needed, especially in propagation nurseries, to ensure that only healthy stock is produced and used in establishing plantations. Fungicides also may be appropriate to reduce inoculum in plantations, but long-term controls using cultural treatments in addition to resistant clones are more desirable.

The Central Iowa plantation used to assess impact of Septoria also was used to test the effectiveness of three fungicides for managing S. musiva. During the first rotation an early and midseason spray of captafol, as well as bimonthly sprays, controlled Septoria canker near the level of the resistant clone (Table 1) (McNabb et al. 1981).

Septoria canker is a serious problem in nursery cutting beds and coppiced stands

Table 1. Results of *Septoria* canker control trials

Clone No. [a]	Ames, IA (plantation)			Freesoil, MI (nursery)			
	Unsprayed check	Captafol spray: early & midseason	Captafol spray: bimonthly	Unsprayed check	Benomyl spray: early season	Benomyl spray: bimonthly	cultivation
	Canker rating [b]			Canker index [c]			
NE 1	5.1	0.9	0.8	.46	.00	.00	.45
NE 299	3.6	0.9	0.6				
NE 298				.00	.00	.00	.07
NE 387	2.9	0.6	0.5	.15	.06	.00	.10
NE 19	0.3	0.0	0.2	.00	.00	.00	.00

[a] NE 1 = *Populus nigra* L. X *P. laurifolia* Ledeb. 'Strathglass' (highly susceptible)

NE 299 & NE 298 = *P. nigra* var. *betulifolia* Torr. X. *P. trichocarpa* Torr. and Gray (moderately susceptible)

NE 387 = *P. candicans* Ait. X *P.* X *berolinensis* Dippel (moderately susceptible)

NE 19 = *P. nigra* cv. *charkowiensis* X *P. nigra* var. *caudina* Tenore (resistant)

[b] Canker Rating = 0 - no cankers; 0.1-9.9 - increasing numbers of branch and stem cankers; 10-tree breakage and death

[c] Canker Index = Number of infected stumps/number planted

(Moore et al. 1982, McNabb et al. 1982b). Chemical control of this disease was tested in Minnesota in 1980 and 1981. Trees were cut yearly to simulate a nursery cutting bed. Four fungicides and four spray schedules including check plots were randomized within the plots. Benomyl applied monthly or bimonthly at 1 lb. active ingredient per 100 gallons of water resulted in less cankering than any of the other treatments.

On the basis of these preliminary results, we began a control study in 1981 at the poplar nursery of the Packaging Corporation of America near Manistee, Michigan. The objective of this study was to compare clone resistance, and chemical and cultural controls to disease incidence. A 30x300-foot length of a nursery bed was planted with four clones variously susceptible to Septoria (Table 1). Four treatments were randomly assigned among the plots except for the plots designated to be cultivated. These plots were on one end of the nursery bed to facilitate use of nursery equipment. Plots were cultivated as soon as the ground was workable in the spring through the end of May. Benomyl was sprayed on some of the remaining plots either once at the beginning of the season or bimonthly throughout the season; other plots were left unsprayed as checks. Disease data were recorded from the center trees of each plot and the other trees served as buffers between treatments.

No significant results were obtained at the end of 1981 because leaf disease was light on all plots and no cankers were present. All plots were harvested along with the production nursery beds in early winter.

The same treatments were applied in 1982 and data were recorded in September. Leaf disease was greater than in 1981 and stem cankers were present. Previous experience had shown us that Septoria canker prevalence increases as inoculum on fallen infected leaves increases. In addition, greater infection in 1982 also was caused by increased density of stems resulting from multiple sprouts on each stump. Both chemical spray schedules were effective in reducing cankering of susceptible clones (Table 1). Cultivation, however, failed to reduce disease. Clones previously known to be resistant or only moderately susceptible were either healthy or lightly infected.

Spore trapping indicated generally low inoculum levels in the nursery. However, the proximity of the cultivated plots to unsprayed susceptible plot trees provided inoculum that may have caused failure of cultivation to reduce disease. Cultural controls may only be effective in reducing disease if done thoroughly and then only if inoculum from outside sources is absent or light.

Benomyl, as was shown earlier with captafol, was effective in preventing disease development in even the most susceptible clone tested. But, the impact that Septoria canker can have in plantations where chemical controls may not be feasible dictates that only resistant clones be planted where this disease is known to be a hazard.

Intensive Culture Versus Disease Development and Management Implications

Silvicultural systems developed for rapid production of wood fiber can favor the development of disease in some instances. Growers must be aware that conditions that maximize tree growth may increase disease incidence or severity so that production gains over natural stands are severely reduced or completely lost.

Populus, as a genus, is host to many insects and pathogens. Many poplar species and hybrids now being planted are not native to our area. Introduction of exotics has resulted in instances where an endemic pathogen in native poplar stands has caused serious disease problems. For example, S. musiva causes minor leaf spotting of native poplars. In contrast, on many hybrids between the sections Aigerios and Tacamahaca, this fungus not only causes premature defoliation of highly susceptible trees, but also causes cankers on stems and branches. Industrial and research plantings examined thus far in Michigan, Wisconsin, Minnesota, and Iowa have revealed that hybrids involving P. trichocarpa, P. laurifolia, and P. maximowiczii are especially susceptible to cankering. Species of Marssonina are periodically important on native poplars. However, M. brunnea causes a serious leaf disease of many P. X euramericana clones. Susceptible clones can be prematurely defoliated and predisposed to other diseases and to winter injury, especially in the northern portion of the north central region.

We only need to look at modern agriculture and the chemical and cultural treatments needed to control diseases to see the potentially serious risk involved in growing trees in a monoculture at close spacings. Use of clones means that all trees of a susceptible clone can be affected in a disease outbreak. Dense plantings create many conditions that can increase disease

severity (Schipper 1976). Density influences air movement, leaf wetness, and humidity within a plantation--important factors in the infection and development of pathogens (McNabb et al. 1982a). Proximity of trees to each other within a plantation influences rate of spread of pathogens and subsequent development and severity of diseases. Even-age management similarly can increase disease severity because all trees may be equally susceptible to a particular disease at their stage of development.

In the vegetative propagation of poplars, serious disease agents may be moved along with cutting or rooted stock. Viruses, detected in many poplar clones being used, threaten vegetatively propagated poplar monocultures, and steps should be taken to eliminate them from planting stock (Berbee et al. 1976, Van der Meer et al. 1980). We have found that unrooted hardwood cuttings taken from clonal nurseries in the Lake States can be infected with Septoria, Marssonina, and Dothichiza. These serious pathogens can be moved to areas of previously uninfected trees. Fungi that are weakly parasitic on poplars such as Cytospora and Phomopsis can weaken improperly stored cuttings so that they produce plants susceptible to other stresses (Ostry and McNabb 1982).

Cultural treatments such as plowing, discing, and irrigation also can influence disease development. Thin-barked poplars can be easily wounded by implements, creating entrances for canker and decay fungi. Plowing may kill or reduce soil microbiota such as saprophytic fungi that would otherwise limit soil-borne pathogen populations. Irrigation, especially overhead systems, may increase foliage diseases because of possible increased spore dispersal and infection resulting from longer periods of leaf wetness.

Poplars growing in an agroecosystem are subject to conditions much different from those in a natural, dynamic ecosystem. Intensive culture systems can create an imbalance, resulting in rapid development and multiplication of pathogens. We are growing a susceptible host on which several potentially damaging pathogens are present. Manipulating the environment around these trees can be extremely important because the environment is a controlling influence on pathogens as well as on the host. Vigorous trees can generally tolerate greater incidence of pathogens and insect pests. Tree vigor, disease incidence, and pathogen and insect populations must be monitored under the various cultural systems used to guard against an imbalance that may cause an insect or disease problem to develop.

Summary and Conclusions

Many pathogens of hybrid poplars have been identified in the north-central region. Some have no apparent impact on tree growth or quality. Other pathogens may be of periodic importance. These need to be monitored so that control actions, either in the current rotation or the next, can be taken to minimize damage. Diseases can increase to unacceptable levels in the event of a change in the host, environment or pathogen. A few pathogens are, however, usually destructive to susceptible trees, reducing tree growth, quality and survival. The risks associated with these pathogens must be considered in any planting plans. Of importance is management's objective in growing the trees: what will be the use of the wood produced?; are quantity, quality, or both important?; how long will the trees be grown?; will the stand be coppiced? These are important questions to consider in terms of diseases impact and disease control. Some of the fastest growing trees we have studied are also the most susceptible to one or more diseases. These diseases pose some threat to trees grown on short rotations, but they may cause serious problems for trees grown on longer rotations. Septoria, for example, may or may not adversely affect management's objectives. Defoliation and growth loss from the disease are severe on only the most susceptible clones, and cankering of plantation trees usually is serious 3-4 years after planting. Therefore, susceptible clones can be grown on mini rotations, but not in shelterbelts or on longer rotations. Wood fiber quality of cankered trees is satisfactory for fuelwood or lower quality paper, but not for high-quality paper. Septoria infection is much more severe in coppiced stands so coppicing highly susceptible clones is highly risky.

Proper planning before planting, including selection of clones with resistance to important diseases, and good management aimed at maintaining high tree vigor will avoid many future problems. Integrating disease control into silvicultural practices is the most promising strategy. Higher economic returns from intensively managed hybrid poplar plantations in the future will justify disease and insect control and give managers more flexibility in dealing with pest problems.

Acknowledgement

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SOME IMPLICATIONS OF POPULUS INTENSIVE CULTURE ON NONGAME BIRDS

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Abstract.--Intensive culture of Populus will affect nongame bird habitat. Conversion of old fields to Populus plantations will destroy habitat favorable to certain species and produce habitat that will attract different species. Effects of this conversion can be lessened by planting plantations with irregular shapes and by leaving patches (.4 hectares) of existing vegetation when plantation size exceeds 60 hectares.

INTRODUCTION

Demand for wood and wood products has increased rapidly in recent years. More and more of the traditional "wild" land is beginning to serve a multitude of needs to our complex society. Management of land for aesthetic purposes, game habitat, camping, snowmobiling, skiing, and water and soil conservation all have potential conflicts with efficient growing and harvesting of timber. According to Davis (1979) competing uses for land have been and will continue to be one of the most important influences on the survival of America's wildlife resources. To partially meet the increasing demand for wood, a silvicultural system called short-rotation intensive culture (SRIC) is being explored. Large plantations of intensive cultured poplars (Populus spp.) planted by paper companies and other private land owners may have important effects on nongame birds.

INTENSIVE CULTURE CHARACTERISTICS

Intensive culture techniques for trees are now being explored. One method is similar, at least initially, to farming traditional row-crops. Existing vegetation is removed and the site is sprayed with a non-selective herbicide, plowed and disked the fall before planting. In the spring, the field is redisked and a pre-emergent herbicide such as linuron is applied just prior to planting unrooted cuttings.

Nitrogen fertilizer is applied annually at a rate of up to 170 kilograms per hectare in a split application (June and July). The plantations are irrigated to maintain a soil moisture tension below -0.5 bars. Insecticides may be used to control serious insect outbreaks if necessary.[2]

Optimum spacing for the trees appears to be between 1X1 and 2X2 meters. Such spacings provide for complete canopy closure during the second year so that competing vegetation will be shaded out. In trial plantations established at Rhinelander, Wisconsin, herbaceous vegetation is almost completely suppressed due to shading by the third year.[3]

Tree growth is rapid with heights reaching 3.6 meters after two growing seasons and over 9 meters after 5 years. Estimated rotation time of plantations varies from

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8 to 15 years depending upon spacing and desired tree size. After harvesting, the stumps will be allowed to coppice (sprout). Regrowth is very rapid and by the end of the first year, lack of light should prevent herbaceous vegetation from growing beneath the trees.

An alternate site preparation technique, the no-till method, is being tried by Packaging Corporation of America (PCA). In this procedure only chemicals are used to control weeds and to prepare the site for planting. Fields are sprayed with a non-selective herbicide the year prior to planting. Planting material consists of rooted stock, 1.3 cm in diameter X 38 cm tall. Once the trees are planted and prior to any germination of annual weeds a herbicide is applied.[4/] Additional herbicide treatments may be required in June and again in late July to control weeds. Spacing at PCA is about 3X3½ meters for a planting goal of 625-900 trees per hectare. In this method, it may take up to 7 years to eliminate herbaceous vegetation.

Plantations of fast growing poplars will likely have characteristics that will have major effects on birds, both those within the plantation and those found in adjacent areas. The impact of these plantations will be due primarily to site preparation to establish the original plantations and physical structure of the established plantations.

ESTABLISHMENT OF ORIGINAL PLANTATIONS

Economics dictate the areas that will be planted to SRIC. Abandoned pastures and fields are likely sites for plantations. Site conversion of low producing or non-producing woodlots to more economically profitable plantations may also take place. Morin indicates that at the present time idle land is plentiful but very expensive.[5/] This determines, to a large extent, the number of acres that industrial users will purchase and plant. Morin also mentioned that private landowners may be interested in fast growing poplars as trees for shelter belts and as a source of firewood for home heating. However, land that is suitable for good northern hardwoods is not likely to be converted to fast growing poplars. Practically, the sites that are best sites for SRIC are also the best sites for other uses (farming, hardwood production or natural regeneration).

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Field studies on the environmental effects of intensively cultured tree plantations are just beginning. Curtis (1978) indicates a need for research that could provide indices of quantitative avian use of forest habitats under various management systems.

Initial effects during the conversion of fields and forest openings to *Populus* plantations will have a distinct impact on the existing habitat. Wood and Niles (1978) indicate intensive culture site preparation for planting essentially eliminates all bird habitat for a period of time. Bird activity that does exist on a newly planted site generally will be restricted to feeding on worms and insects that are exposed by the tilling of the soil. During the early growing seasons some avian species requiring early successional stages may benefit. Fields prepared by the no-till method will still have dead vegetation on them in which some species may forage and nest. In addition the dead vegetation provides cover for small rodents which in turn may be preyed upon by various raptors. Use of available niches during succession of plantations may have an overall favorable effect on the number of birds and species in the area.

Both methods of site preparation completely change the existing habitat. This is of particular concern for birds of Wisconsin fields (Table 1) that are in the 1980 Blue List (Arbib 1979). The Blue List is a list, compiled by the editors of *American Birds*, of species recently or currently giving indications of non-cyclic population declines or range contractions.

Table 1.--Blue listed birds (1980) of Wisconsin fields.

Northern Harrier	*Circus cyaneus*
Upland Sandpiper	*Bartramia longicauda*
Short-Eared Owl	*Asio flammeus*
Sharp-Tailed Grouse	*Pedioecetes phasianellus*
Eastern Meadowlark	*Sturnella magna*
Dickcissel	*Spiza americana*
Vesper Sparrow	*Pooecetes gramineus*
Grasshopper Sparrow	*Ammodramus savannarum*

A second consideration becomes apparent if plantations should be established in upland forest openings. Taylor and Taylor (1979) point to the controversy that exists concerning forest openings: to timber managers they represent non-producing land; to wildlife managers they represent a unique vegetative association of the forest.

The importance of woodland openings to bird life has been discussed by Lay (1938). Avian diversity varies in forest openings. Size of the opening and the surrounding vegetation (type and size) have an important influence on the animal species present (Bond 1957). Taylor and Taylor (1979) report that vegetation species composition of openings seems to be less important than the overall structure of the vegetation. Bird populations have been observed to increase while physical size of the opening was reduced (Evans 1978). The population increase appears to have been the result of the development of more suitable nesting sites as the field passed through successional stages.

If forest openings are converted to SRIC sites or if large openings are interspersed with plantations the type and amount of edge will change. Edges have been considered especially productive areas for many species of birds. Lay (1938) found margins of clearings to contain 41% more species and 95% more individual birds than do the corresponding woodland interiors. Lay indicated that the edge effect usually extends less than 93 meters into the interior of the woodland.

PHYSICAL STRUCTURE OF PLANTATIONS

SRIC plantations will be even aged monocultures with little or no understory, herbaceous vegetation, fallen or dead trees and snags. All these characteristics reduce bird diversity and numbers. Wood and Niles (1978) indicate that simple plant communities such as an even aged monoculture will not support as large a number of bird species as a more heterogenous community. Habitat and niches which allow diversity are simply not present.

Moss (1978) compared three areas showing increasing structural diversity. His conclusions were that maximum density of song birds depends on diverse structured woody vegetation with a good understory. He found four bird species in spruce (Picea) plantations that lacked an understory, eight bird species in more open spruce plantations and fifteen to eighteen species on multi-structured mixed wood plots. Moss (1978) reported that von Haartman found that the two most important factors to influence song bird diversity are vegetation structure (particularly the presence or absence of an understory) and tree species.[6] Probst (1979) has indicated that tree species composition of eastern deciduous forests has little effect on bird communities because most birds select habitats by vegetation structure. He does mention that smooth barked tree species (some Populus) may contain fewer arthropods than those with rough bark. This could limit bark foragers on some plantations.

Wesley et al (1976) compared bird populations in three areas in Mississippi. One area was a natural riverfront hardwood stand characterized by pecan (Carya illinoensis), green ash (Fraxinus pennsylvanica), box elder (Acer negundo) and sugar berry (Celtis laevigota). The second area was a thinned cottonwood plantation (every other row of trees removed from plantations with 3X3 or 3.6X3.6 meter spacings) and the third area was an unthinned cottonwood plantation with tree spacings again 3X3 or 3.6X3.6 meters. Both the thinned and unthinned plantations had high understory biomass. Songbird numbers were significantly less in the unthinned plantation than they were in the thinned plantation or the natural stand. Preliminary studies showed plantations to be favored by certain species and avoided by others. Wesley et al. (1976) cautioned that while their data indicate a general preference for the natural riverfront hardwood stands it does not necessarily follow that cottonwood plantations are detrimental to songbirds. While plantations remove one type of habitat prized by some species, it may provide food, cover and nesting sites vital to other species.

Temple et al. (1979), while not dealing specifically with plantations, details some disadvantages of even aged forest management that apply to intensive culture. He indicates that vertical diversity is reduced with a concomitant reduction in the number of foraging opportunities available to birds. He also discusses the effects of reducing or eliminating dead or diseased trees from an area. The loss of insects and cavities affects a number of bird particularly members of the winter bird community which feed on insects in bark or wood.

Traditional long rotation forestry that removes small stands of timber through selective logging or clearcutting has a major impact on the avian community (Anderson 1979). Overall the removal of timber attracts edge species and provides a temporary mixture of both forest specialists and edge generalists. Conner and Adkisson (1975) in studies in Virginia found breeding bird diversity to be lowest in a one year old clearcut (mixed oak forest) and highest in a seven year old clearcut. They also noted that forest dwelling birds first appeared in a twelve year old clearcut. The

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[6] L. von Haartman, "Population Dynamics," Avian Biology 1, D.S. Farner and J.R. King (eds.), London, Academic Press, 1971, pp. 392-459.

short rotation periods (eight to fifteen years) on the Populus plantations may have similar effects.

Disturbance of woodlands adjacent to SRIC plantations may also occur. Robbins (1979) clearly documents the effects of forest fragmentation on certain species of birds. When plantations are interspersed in isolated plots, harvesting of trees will impact the areas where cutting is taking place as well as in the areas where access trails are located.

Practices are possible that could enhance plantations to certain species of birds. "Island refuges" of existing trees and scrub about 0.4 hectares in size could be left in various places in large plantations (60 hectares +). Williamson (1970) indicates that the diversified habitat provided will enrich bird life, even in extensive new forests. Connor and Adkisson (1975) found that leaving dead snags, slash and other debris scattered in certain areas of the plantation also benefits bird life.

A second practice that may serve to increase bird diversity is to allow small openings (less than fourteen hectares) to remain in forested areas. Taylor and Taylor (1979) say the present objective is to maintain 1-5% of the forest land in upland openings. These openings should be managed as part of the forest and should furnish particular life forms including grass, and grass-shrubs as well as stumps, snags and hollow logs.

SUMMARY

Intensive culture of Populus will impact bird communitites. At the present time it appears the major impact will be on bird species of old fields and pastures. The conversion of these areas to SRIC will completely change the niches found in each area. The loss of field niches will impact a number of species and is of particular concern for the birds found on the Blue List (Table 1) and other bird species that nest or feed on the grasses and weeds of the field. Other species not found in fields may find conditions in the plantations favorable so that the total effect on number of bird species in an area may not decrease and may actually increase.

It should be noted that effects of monoculture on wildlife are closely related to the size and shape of the plantation. If plantations make up only a small portion of the total defined land area effects on wildlife including songbirds may be beneficial. Conversely if plantations become the dominant land use pattern the wildlife will be adversely affected. If plantations have irregular shapes and provide lengthy edges this will help mitigate the influence of size as will leaving small stands of existing trees and shrubs.

Wesley et al. (1976) indicates that there is a need for continued study in order to answer the questions about cottonwood plantations as wildlife habitat. Present studies should provide data on the use of plantations by each bird species throughout the growth (age) cycle. Use of the plantations, by birds, on a seasonal basis is also a question being investigated.

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SYNOPSIS OF UTILIZATION RESEARCH ON SRIC RAW MATERIALS

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The take-home message of this paper is this: Raw materials produced using SRIC are suitable for many reconstituted end products. Juvenility, rapid growth, and bark contents do not greatly hinder the usefulness of the raw materials. In the future, increased industrial acceptance of SRIC methods and materials should be a major thrust and is discussed.

The purpose of this review is to see where we have been, where we are now, and where we are going in the future. Initially, the purpose of SRIC (short rotation intensive culture) was to see how productive woody plants could be. How fast could we grow woody plants to satisfy demand for raw materials. Utilization research became important when we realized that SRIC could produce large quantities of biomass, but the biomass was different from that produced by traditional forest management methods. We needed to know if SRIC raw materials were suitable for forest products; which I'll address as the main body of this paper. I'll end the paper with speculation on how to increase industrial acceptance of SRIC methods and materials in the future.

The title of this paper starts with the word synopsis. By definition, a synopsis is a condensed statement. The condensed statement and the take-home message of my paper is this: Raw materials produced using SRIC are suitable for many reconstituted end products. Let's examine the words used in this statement. First, I used the verb "are," not "maybe," because much research has proven acceptable products can be made from them. Next, the word "suitable" was used, not "best," because products can be made that are within industry standards or guidelines, but there are limitations. The word "many" instead of "all" was used because there have been some failures, but mostly successes. Next, "reconstituted" was used to show these materials are best for products other than those made from solid wood. Lastly, "end products" was used instead of "forest products" to show that uses are broader than traditional uses, such as chemicals and animal feed.

The take-home message is a strong statement. But it is not nearly as novel or controversial as it was in 1976 when some of us in the SRIC program theorized the statement was true. At the 1976 review, I presented a paper on utilization advantages of SRIC materials. Most of the speculation in that paper has proven true, and some warrants repeating. At that time, many people thought that juvenile materials were unsuitable for utilization. However, in the interim, research by us in the SRIC program and by others on different raw materials has shown juvenile materials can be quite acceptable. In fact, some of the strongest and loudest opponents have become advocates of juvenile materials.

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The changing viewpoints on juvenile materials is not surprising when the nature of the material is considered and understood. Juvenile materials have shorter fiber (cells) than older material. Therefore, in papermaking, there is less opportunity for fiber crossings to form interfiber bonds. The strength of interfiber bonds control most paper strengths, not the strength of the fibers themselves. However, the average cell wall thickness of juvenile material is less than older material. These thin cell walls readily collapse into the desired ribbon shape to provide a large surface for bonding, and they are pliable so the fibers can conform to each other to form strong interfiber bonds. Even though there are less bonds due to the short fibers, the bonds present are strong enough that the net result is paper strength properties that are acceptable and within most product standards.

The conformity is also evident in products other than paper. In waferboard, in which particles instead of fibers are used, the conformity allows excellent bonding between particles, and therefore high strengths in the boards produced.

There are additional erroneous conventions other than juvenility about SRIC materials. Rapid growth is sometimes thought to be detrimental. In most conifers, accelerated growth decreases the proportion of summer wood produced, thereby reducing mechanical strength properties. The reduction in mechanical strength affects the suitability for solid wood products. The convention on rapidly grown conifers should not be applied to SRIC in which mainly Populus is grown and which is not intended for solid wood products. Populus is a diffuse porous species and a main effect of accelerated growth is to prolong juvenility.

SRIC materials will be harvested by whole tree methods. They have high bark contents because of the small diameter, branchy stems. Yet, the bark is different and not as detrimental as bark from older stems. The most troublesome cell types in bark increase with increasing age, and the young stems harvested using SRIC have not developed many detrimental bark cells. Further, another problem with conventional whole tree materials is the amount of grit contained in them. The harvesting machines and methods for SRIC materials will greatly decrease grit contents because the materials will not have as much contact with the ground.

To gain increased industrial acceptance of SRIC, corporate decision makers need to be made aware of advantages inherent in both SRIC systems of fiber production and in the SRIC raw materials themselves. SRIC systems and materials must compete with existing, conventional methods and materials. Let's examine the "market leverage" of SRIC systems and materials which might allow penetration into the market held by traditional methods and materials.

For SRIC materials, juvenility, rapid growth, and bark and grit contents were discussed previously. A great advantage of SRIC material is uniformity. SRIC minimizes variability from the three main sources of variation in woody plants; genotype, age, and culture. The uniform raw materials can be processed with conditions closely tailored for them, thereby increasing yields and gaining efficiency. Also, through selection, clones can be grown that are best suited for a particular process and product --- engineering from the growing plant, through the processing plant, to the final product.

For SRIC systems, some of the advantages are self-evident. Transportation costs can be reduced if plantations are located near mills. Harvesting costs can be less. The machinery needed is smaller and less expensive than traditional harvesting machines because the trees in SRIC are smaller and don't vary as much in size.

A major advantage is the insurance value. If a mill has plantations on their own land, they have a readily available fiber supply source and are not as much at the mercy of labor or weather. This guaranteed supply protects their huge capital investment in the mill or plant. Also, because these plantations are grown on good sites, little affected by weather, the millyard needs less inventory and less capital is tied up.

Some of the above advantages of SRIC materials and systems can be quantified and used in economic analyses. Others are harder to quantify, but are still important in decision making processes. We need good information to provide firm numbers for economic analysis. An analysis should address all steps from plantation establishment through to the

final product, to account for tradeoffs and compromises in and between steps. With firm numbers, a final scenario or thought process in a corporate decision maker's mind might go as follows when he is comparing SRIC methods and materials to those of more traditional forest systems:

-My cost of growing the raw materials may be greater with intensive cultivation and fertilization, etc., but because of high growth rates and short rotations I'm getting greater and quicker rates of return, I need less land to grow my raw materials on.

-My harvesting cost will be less, because of the smaller and less expensive machines I need to handle the small trees.

-My transportation cost will be less, because I'll locate my plantations close to my mill.

-My inventory cost will be less, because my plantations are readily available and growing on good land that is operable during most weather conditions. I need less millyard inventory to ensure my plant can continue to operate.

-My processing costs may be greater, because the high bark contents may decrease yields and I'll need additional processing equipment, but the material is uniform and I can be highly efficient in the processing and I can select and grow materials that are suited for my process.

When I add up all these factors, the net result may be a higher balance on the bottom line of the ledger sheet. I'm vertically integrated, and each vertical step serves as insurance to protect my investment in the next step. I'm less dependent on others such as wood suppliers and I'm little affected by weather. All in all, it's not a bad position to be in, and certainly warrants looking into SRIC.

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A PROTOTYPE HARVESTER FOR SHORT-ROTATION PLANTATIONS

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Abstract.--A promising approach to increasing the supply of wood fiber for pulp and energy is short-rotation intensively cultured (SRIC) forestry. To apply the principles of agriculture to the growing of wood fiber, designers of harvesting equipment must consider a unique set of operating criteria. This paper summarizes the design criteria relevant to the SRIC concept and describes the results of initial trials with a prototype short-rotation harvester.

INTRODUCTION

Short-rotation intensively cultured (SRIC) plantations are a promising way to increase the supply of wood for fiber and energy in the future (U.S. Department of Agriculture, Forest Service 1980). To be applied commercially, SRIC systems must have technically and economically feasible equipment and systems to carry out the required silvicultural treatments and perform the necessary harvesting and processing operations.

The harvesting of wood fiber grown on SRIC plantations has received little attention. One advantage of SRIC systems is a completely mechanized harvesting operation to reduce labor costs and make a year-round operation more practical, but the mechanics of implementing the harvesting have not been extensively studied.

The forest engineering project at the Forestry Sciences Laboratory, Houghton, Michigan, has designed and fabricated a prototype harvester for SRIC plantations. This prototype is basically a test rig to evaluate the feasibility of several equipment concepts included in its design and also to develop a base of design criteria for an eventual commercial harvester.

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CHARACTERISTICS OF SRIC PLANTATIONS RELEVANT TO HARVESTER DESIGN

Short-rotation intensively cultured forests are expected to consist of selected, rapidly growing, hardwood tree species. The crop would be harvested at appropriate rotations, and the succeeding crops would arise by coppicing (sprouting from stumps), precluding the need to replant after each harvest.

Suggested plantation scenarios have row spacings ranging from 1.2 to 2.4 m with spacings between trees within the rows ranging from 1.2 to 1.8 m. Anticipated rotation age ranges from 8 to 15 years depending upon the spacing option chosen. These combinations will produce trees ranging from 10 to 25 cm in diameter at groundline and from 10 to 20 m tall. Most of the trees will be in the 10- to 20-cm diameter range, but some along the edges of the plantation may reach 30 cm in diameter. These stands are expected to produce from 10 to 15 dry tonne equivalents of biomass per hectare per year from trees ranging from less than 50 kg to more than 200 kg in the first harvest. Tree size will decrease with successful coppicing of the stands, and number of trees per hectare will increase.

Most envisioned SRIC systems use coppicing to regenerate the stand after harvesting. To ensure a suitable level of regeneration, the harvester will be required to maintain a preset stump height, up to 25 cm. The stump must have a clean-cut surface (such as would be produced with a saw). Lateral pressure against the stump will have to be minimized to avoid disturbing roots below ground. The harvester will have to stay within the rows of the plantation to avoid damaging the stump system.

Because the coppicing of the original stumps to produce new sprouts may produce a wider plant structure in subsequent harvests, the harvester will have to be able to handle a sprout cluster up to about 65 cm wide.

The need to obtain an adequate level of coppicing may limit the harvest season to the dormant season when ground conditions may be adverse. To aid mobility of the harvest equipment and avoid excessive damage to the site and root system, vehicle ground pressure will have to be minimized, possibly to as low as 15 to 20 kPa in extremely low bearing sites. The number of vehicle passes over the stand during harvest should also be minimized to avoid rutting, soil compaction, and other site damage.

Most sites envisioned for energy farms contain terrain suitable for vehicle travel. The harvester will probably only have to be capable of operating on side slopes up to 10 percent and direct slopes up to 20 percent. The plantations will also probably be free of rocks in the operating zone of the harvester felling device.

APPLICATIONS OF CONVENTIONAL EQUIPMENT

The biomass produced in SRIC forests may be handled and transported as whole-tree chips. The chips are suitable for most subsequent conversion and processing operations.

Whole tree chipping is a highly mechanized system capable of producing large quantities of wood per man-day. Besides the advantages of high productivity and reduced labor requirements, the yield per hectare of usable wood is greatly increased due to the additional amounts of fiber recovered from the tops, limbs, and other residue materials normally left in the woods after a conventional roundwood operation. Additionally, the site is left in a clean, esthetically more acceptable condition that facilitates subsequent silvicultural operations.

The basic whole-tree chipping system consists of feller/bunchers that sever the trees and accumulate them into bunches, grapple skidders that move the bunches from the forest to the chipper, portable chippers that operate at a woods landing to reduce the whole trees to chips, and chip vans that transport the chips to the mill (fig. 1).

An earlier study by Mattson (in preparation) used simulation methods to study the potential for utilizing whole-tree chipping to harvest SRIC plantations. The results of the simulator trials showed that tree size is the major factor affecting productivity and cost. Current harvesting equipment requires large trees to operate economically.

The felling/bunching phase of the harvesting operation is the area where current technology is the most deficient with respect to harvesting small trees. Current skidding/forwarding and chipping equipment is designed for multiple-tree operation, so it can be adjusted to the design parameters presented by the small trees of an intensively cultured stand. However, the basic design of conventional shears is based on handling one tree at a time. For stands of small trees, this restriction limits the potential productivity of the equipment.

The development of felling/bunching equipment that operates on a continuous or multitree basis is the most significant research need in the area of harvesting SRIC fiber.

HARVESTER CONCEPT CONSIDERATIONS

The requirement of coppicing to produce subsequent crops from the original stumps in SRIC plantations may preclude the use of a conventional whole-tree harvesting system as discussed previously. Preliminary studies have shown that the small stumps found in SRIC plantations are susceptible to mechanical damage by equipment working in the stand (Crist et al. in this proceedings). Skidding in particular, as it is typically done, would be unacceptable in an SRIC stand because the machine's maneuvering and turning would certainly cause excessive damage. Skidding the loads of trees across the plantation would also be likely to cause excessive damage. Because of the possibilities of damage, harvesting operations would probably have to be laid out so that whatever machinery is involved can stay tracked between rows of the plantation and carry out its required function while making a pass through the plantation.

The number of passes through the stand should also be minimized to minimize soil compaction---so a machine needing only one pass would be desirable. Such a machine would be capable of severing the stems and simultaneously collecting the severed stems and forwarding them to the plantation edge.

A machine that could simultaneously fell and chip the trees and transport the chips to the plantation edge would be much heavier than a machine that only fells and collects the severed trees and forwards them to the plantation edge. The lighter machine could be expected to cause less soil compaction and cost less. Considering that the harvester will probably be used only for a portion of the year,

a smaller, less costly machine would be preferable. If the harvester could be built to utilize a standard prime mover as its motive and functional power source, it could cost even less.

The possibility of the harvest being limited to the dormant season has some definite implications for the design of the harvesting equipment because the fiber must be stored for year-round use. Storing the material on the edge of the plantation would eliminate any initial transport because the harvester could offload right at the storage site, also eliminating the need for extensive storage at the use point. The harvesting would also be more efficient because any delays caused by interaction with the transportation system would be eliminated.

From the utilization standpoint, collecting the whole trees at the plantation edge for storage appears to have some advantages over chipping the material in the stand and then storing the chips. Also, chips are not a preferred form for long-term storage because problems with heating of the chip piles and deterioration of the material can occur. Dirt and grit can get into the material when chips are recovered from the ground for loading and subsequent transport to a use point. If the trees are stored in whole-tree form at the plantation edge, conventional chipping equipment can efficiently convert them into chips and load the chips onto trucks for transport. Also, the whole trees could be converted into an alternate product form such as chunks or blocks, which may be preferred for a particular application such as burning (Arola et al. in this proceedings).

A PROTOTYPE SRIC HARVESTER

The prototype harvester is composed of three major parts: a felling head, a directional felling device, and an accumulating section (fig. 2). The felling head on this prototype is constructed around an elongated two-flute milling cutter with spiral cutting edges, or auger cutter (fig. 3). It severs the stems by milling out a section of the trunks equal to the cutter diameter, 5 cm in the case of this prototype. The advantages of this device include the ability to cut anywhere along its 0.6 m length, no need for an anvil, and a fairly clean cut on the residual stump. The cutter is relatively heavy and compared to a circular saw, shouldn't be as vulnerable to damage from occasional contact with foreign objects or require sharpening as often.

The auger cutter is mounted in a movable subframe assembly that also contains the auger drive motor and a cutting height adjustment feature. The movable subframe assembly is mounted to the harvester in such a way as to allow relative motion in the direction of harvester travel between the harvester and the auger cutter. This is accomplished by the use of two guided shafts that form part of the forward section of the movable subframe. Each shaft is supported by two linear motion bearings contained on the rear section of the assembly. The rear section is pinned to the harvester to allow for different auger cutter height settings and to permit the subframe to float over irregular ground contours. The interface between the forward and rear sections of the auger cutter subframe assembly, in addition to the linear motion bearing and shafts, is two air cylinders. These cylinders keep the forward section extended to its outmost position and provide three functions: First, they allow for the setting of the maximum lateral load applied to the tree during the cutting process; this factor controls the chip thickness and horsepower requirements of the auger cutter. A large air reservoir incorporated in the harvester frame maintains an almost constant air pressure in the cylinders regardless of their relative position. Second, the cylinders allow for the forward section to return to the extended position once severing is completed. Their third and probably most important function is to allow for relative motion between the harvester main frame and the auger cutter. This is of utmost importance in obtaining good production rates. An ideal harvesting machine should be severing trees 100 percent of the time without any travel time between cuts. A rigidly fixed cutting device can require the harvester to slow during each cut and then speed up between cuts. The auger cutter retraction feature allows the cutter to sever the tree at its own rate while the main harvester frame travels at a steady rate along the row of trees. Production rates depend on tree spacing and size. The size or diameter of the tree determines the required cutting time which in turn will dictate the maximum harvester ground speed. By proper adjustment of the variables, cutter speed, feed pressure, and ground speed, the harvester would conceivably approach the 100-percent efficiency rate.

The cutting height adjustment feature consists of a pneumatic tire mounted on either side of the forward moving frame section adjacent to the end supports of the auger cutter. The wheels can be positioned so that stump heights will vary between 5 and 22 cm.

The cutter rotates upward so that stump damage is minimal during severing. The upward rotation also tends to move the butt of the tree rearward onto a shelf mounted behind the cutter. This shelf is an integral portion of

the forward-moving subframe. Once the tree is cut and placed in a vertical position on the support shelf, the directional felling device pushes and tips the tree towards the rear of the harvester. Guides direct the tree so that it falls to rest on the harvester bunks (wide U-shaped forms located at the front and rear of the harvester).

The directional felling device consists of two shafts mounted vertically on each side of the auger cutter. Each shaft has several spring steel blades mounted in a horizontal plane about the axis of the shaft. The shafts and blades rotate in opposite directions so that the cut portion of the tree is directed between the felling guides.

Once the tree has been felled onto the harvester bunks, slow-moving drag chains with tall fingers on each bunk move the tree towards the left side of the machine. When a small collection of trees has accumulated at the end of the drag chains, a packing arm on each bunk picks up the load and places it at the extreme left of the bunk and packs it, along with other small loads, into a bundle. Once a full load has been established in the packing area or at the end of a row of trees, the load is offloaded onto a pile for storage and subsequent processing and/or transportation to the use point.

The harvester was constructed so that several processing concepts could be tested; therefore, a drive and power system was not included as part of the main machine. Because most woods-working equipment is hydraulically operated, we decided that the harvester should also function hydraulically. To field test the harvester, all we needed to do was obtain the use of a prime mover with adequate hydraulic power and capacity to operate each of the harvester functions. Another advantage of a hydraulic system is the versatility of most hydraulic components. Motor and cylinder speeds can be controlled simply by monitoring and adjusting the oil flow to them. Motor torques and cylinder forces can be controlled by simply regulating the oil pressure. Because these controlling and regulating devices are commonly installed as part of a standard system, additional components are not necessary. If an entirely mechanical system were incorporated, then additional belts, pulleys, and other components would be necessary to vary the system functions.

Briefly, the harvester's functions are controlled by the following devices: the auger cutter is driven by a Abex-Dennison[3] spring vane motor, Model M4C. The motor is capable of 2500 psi at 2500 rpm continuous operation and 2500 psi at 4000 rpm intermittent. Because the motor is of a cartridge construction, various torque and speed combinations can be obtained. The "egg beaters" or directional felling devices are driven by Char-Lynn hydraulic motors, Model "H" of the gerotor design. The drag chains are operated by the same type of motor. The pack arms are controlled by hydraulic cylinders.

RESULTS OF INITIAL TESTS

Once the "bugs" were worked out of the auger cutting system, it performed remarkably well. The original auger cutter did not have enough chip space causing it to plug with chips and not feed properly. The cutter was reworked to deepen the gullet and enlarge the chip space. We also encountered problems with the first version of the auto retracting system and completely redesigned the sliding guides. With the auger running at 2000 rpm, the pressure relief set at 2500 psi, and with 60 psi in the air cylinders, the cutter cleanly severs a tree, leaving a relatively smooth stump surface. The forward moving frame section retracts effortlessly when vehicle speeds exceed the cutting speed.

The directional felling device was less successful; every so often a tree would not drop directly on the bunk. Usually the top of the tree would miss the rear bunk. Although this was not a serious problem, it could lead to delays and jams with a production-style machine. The bunk collection system (drag chain and packing device) worked as it was intended.

RECOMMENDATIONS FOR FURTHER RESEARCH

The harvester worked well for a first prototype, although several problems still exist in the directional felling phase. For this reason we are continuing with research into additional concepts for short-rotation harvesters. Presently, we are considering two concepts to combine the directional felling and collection phases into a single operation using an accumulator for collecting the trees in a vertical position behind the cutter. This approach could possibly increase the harvester's load carrying capacity while decreasing its physical size. Other concepts utilizing multirow harvesting will also be considered.

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[3] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.

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Figure 1.--Schematic of a typical whole-tree chipping operation.

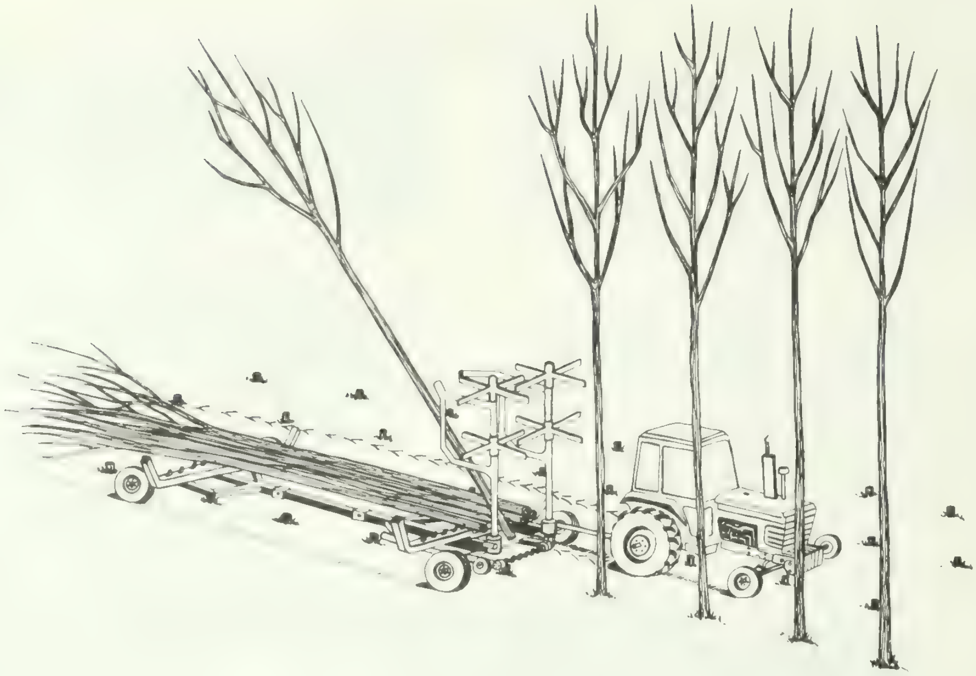

Figure 2.--A prototype SRIC harvester.

Figure 3.--Felling head of prototype SRIC harvester.

PROTOTYPE WOOD CHUNKER USED ON POPULUS 'TRISTIS'

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Abstract.--Populus 'Tristis' trees grown under short-rotation, intensive culture were sampled and chunked in a prototype experimental wood chunking machine. Data presented describe the character of the trees chunked, the energy and power requirements for chunking, and the chunking rate. Specific energy requirements for chunking Populus 'Tristis' are compared with chunking and chipping common Lake States' species from natural stands.

An essential objective of harvesting short rotation, intensively cultured (SRIC) plantations is to convert the trees into a useable form. Whole-tree chippers, which are commercially available, offer one means to reduce SRIC trees to chips for subsequent utilization for pulp and paper or energy. Although chips are used to produce energy they have several disadvantages due to their small particle size, low bulk density, and close layering characteristic that restricts air movement in storage piles or combustors that burn on grates. Chips are also not suitable as furnish for structural flakeboard because of their short dimensions in the fiber direction--they cannot be satisfactorily flaked.

To explore new utilization opportunities for small diameter trees including those from SRIC plantations, forest engineering researchers at the Forestry Sciences Laboratory in Houghton, Michigan, have been investigating new concepts for comminuting wood. A key result has been the development of a wood chunking machine that reduces small trees into particles much larger than chips. Our wood chunker is not yet commercialized, and we are just now introducing the wood chunking concept to industry. Thus, no data exist on the utilization of chunkwood in the composite wood material (CWM) and wood energy industries. Through future research and demonstration projects done in cooperation with industry and other interested organizations, we hope to document chunkwood's application to the wood energy and CWM industries.

Because of the excellent prospects for commercialization of our wood chunking concept, laboratory research was conducted on our prototype machine to determine overall performance and to document the power and energy requirements for several important Lake States' species (Arola et al. 1982; Arola et al., manuscript submitted to Forest Products Journal). The purpose of this paper is to provide similar documentation for chunking intensively grown Populus 'Tristis.'

CHUNKING TESTS AND RESULTS

Our basic wood chunker consists of three 1/4-inch curved blades attached to a driven, shaft-mounted disc (fig. 1). The blades, which vary in depth from zero at the leading edge to approximately 9 inches at the trailing edge, are mounted perpendicularly to the disc face with the trailing edges curved inward. Logs are fed into the blades by hydraulically powered feed rollers. As the disc rotates, the blades sever 2- to 5-inch long chunks from the bolts (fig. 2). We ran the machine at a no-load cutter disc speed of 220 revolutions per minute and a workpiece feed rate of 245 feet per minute.

Populus 'Tristis' samples were obtained from the North Central Forest Experiment Station's Harshaw Forestry Research Farm,

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which is located near Harshaw, Wisconsin, and is managed by the Maximum Fiber Yield Project at Rhinelander, Wisconsin. All material was cut into nominal 100-inch bolts. For each test bolt we determined the small and large end diameters, moisture content, length, and weight (table 1).

By instrumenting the shaft, we were able to record torque, integral of torque, cutter disc speed, and time. From these measurements we calculated the energy per cubic foot of solid material chunked, average torque and horsepower required, and the chunkwood production rate (table 1).

In general, with bolts ranging in diameter from 3.5 to 7.5 inches, the machine chunked wood at the rate of about 30 cubic feet of solid wood per minute and required about 35 horsepower. The mean energy requirement for Populus 'Tristis', with a moisture content of 46 percent and specific gravity of 0.3, was 1.2 hp-min/cu ft.

It took less energy to chunk intensively cultured Populus 'Tristis' than it did to chunk several species from natural Lake States' stands including Populus 'Tristis' cousin, aspen (fig. 3). Though energy requirement data aren't available for conventional chipping of Populus 'Tristis,' the tabulations for aspen and maple clearly show that it takes less energy to produce chunks than chips (table 2).

Table 1.--Results of chunking tests with hybrid Populus 'Tristis.'[1]

Item	Mean	Standard deviation	Minimum	Maximum
Bolt length (inches)	100.2	1.6	99.0	105.0
Bolt diameter (inches)				
Small end	4.3	.5	3.6	5.0
Large end	6.1	.7	5.3	7.4
Weight (pounds)	44.8	11.1	31.3	62.2
Chunking time (seconds)	2.6	.2	2.4	3.2
Moisture content[2] (green basis)	46.5	3.8	40.5	52.5
Specific gravity	.3	.03	.24	.34
Production rate (cu-ft/min)	29.3	4.7	22.7	39.3
Average torque (ft-lb)	832.4	141.8	661.0	1,108.0
Average power (horsepower)	33.5	5.6	26.8	44.1
Energy				
(hp-min/cu ft)	1.2	.1	1.0	1.3
(hp-hr/green ton)	1.1	.1	.9	1.3
(hp-hr/ovendry ton)	2.1	.2	1.8	2.6

[1]Based on a cutter disc speed of 220 rpm and feed rate of 245 feet per minute.

[2]Calculated by TAPPI Standard T18 M-53 (Technical Association of Pulp and Paper Industries 1967).

Table 2.--Comparison of energy requirements for chunking versus chipping.

Species	Chunks	Conventional chips[1]	Energy ratio (chunks/chips)
	- -hp-min/cu ft- -		%
P. 'Tristis'	1.2	--	--
Aspen	1.4	3.8	37
Red maple	2.1	5.5	38
Sugar maple	2.5	7.6	33

[1]Papworth and Erickson 1966.

We conclude that the concept of chunking and the prototype wood chunker have excellent commercial potential--both from wood utilization and equipment development viewpoints. The unique physical character and size appear to give chunkwood some distinct advantages over conventional pulp-size chips. Two key chunkwood opportunities are as an intermediate furnish for the flake board/composite wood product industries and the wood energy industry. We are currently cooperating with the Forest Products Laboratory in Madison, Wisconsin and the Institute of Wood Research at Michigan Technological University in Houghton, Michigan to evaluate the suitability of chunkwood as a source of flakes. This cooperative research focuses only on aspen and dense hardwoods. Similar research should be directed at Populus 'Tristis.' Because the wood energy industry has not yet been exposed to chunkwood as an energy converter feedstock, studies or demonstration projects should be carried out to evaluate the suitability of chunkwood for solid fuel combustors, gasifiers, pyrolyzers, etc. We are seeking the cooperation of the wood energy industry to document this application.

In our opinion, chunking will provide a viable alternative to chipping and will help improve the market potential for small trees from natural and SRIC stands.

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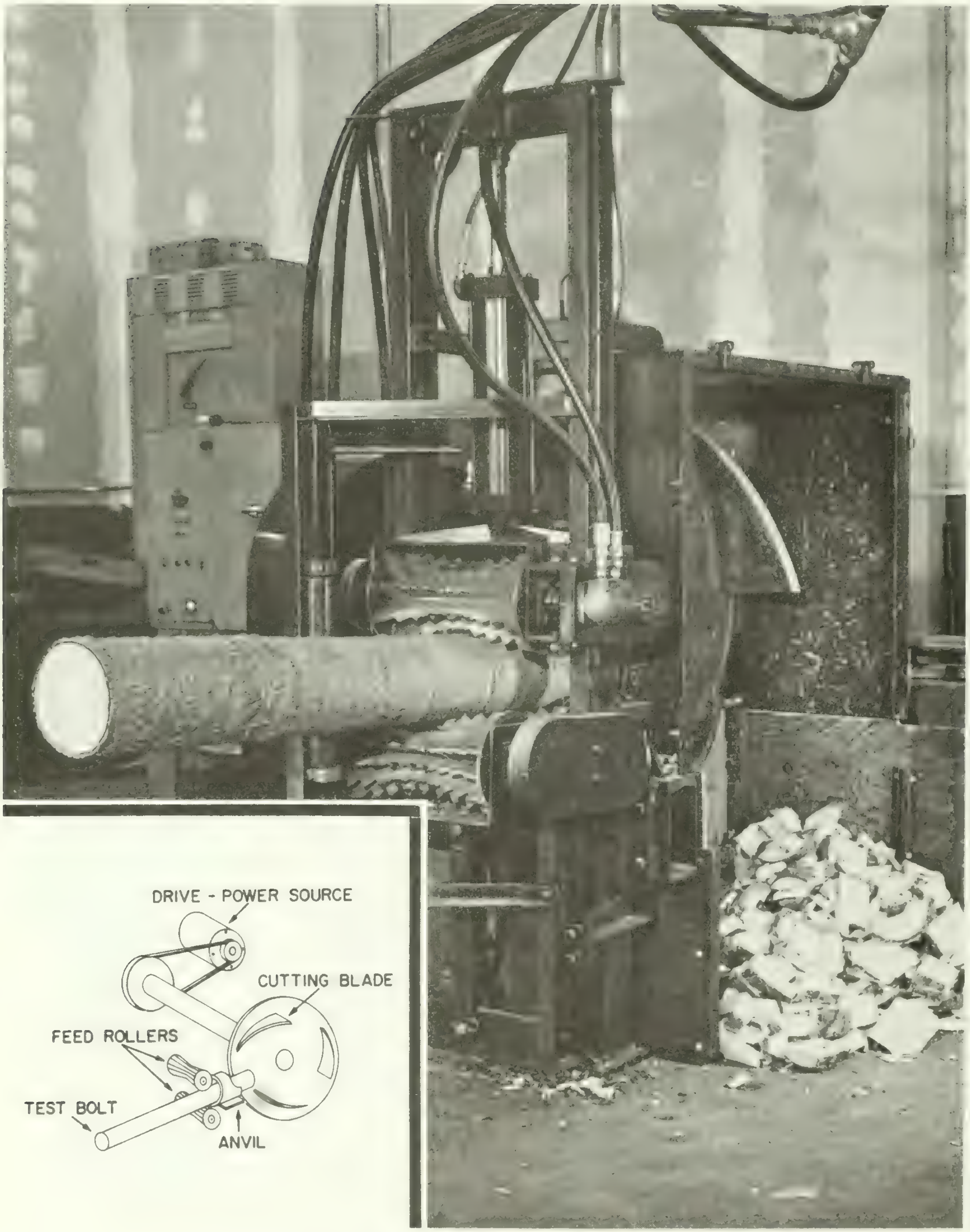

Figure 1.--Photo and simplified schematic of the experimental wood chunker.

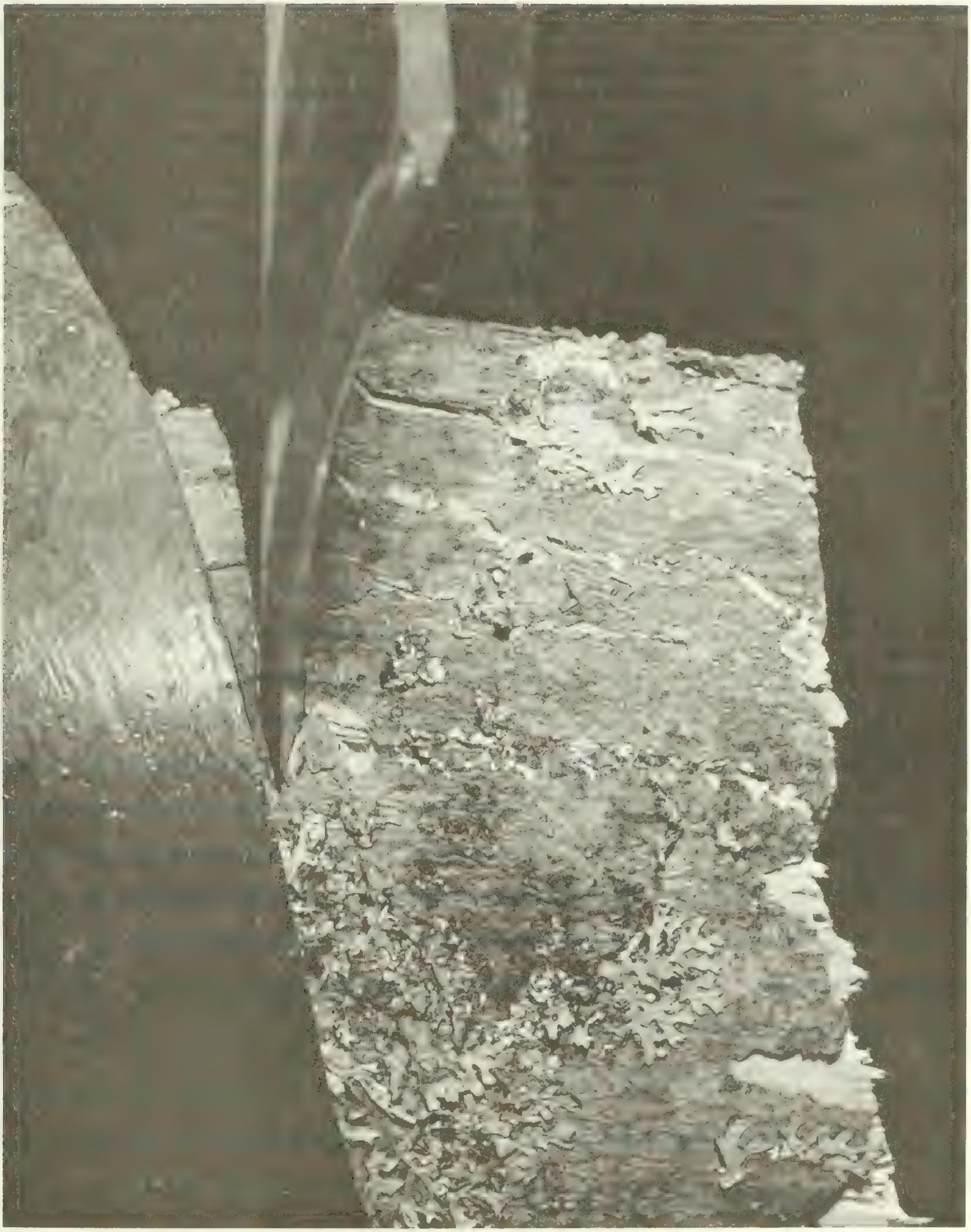

Figure 2.--Chunkwood being severed.

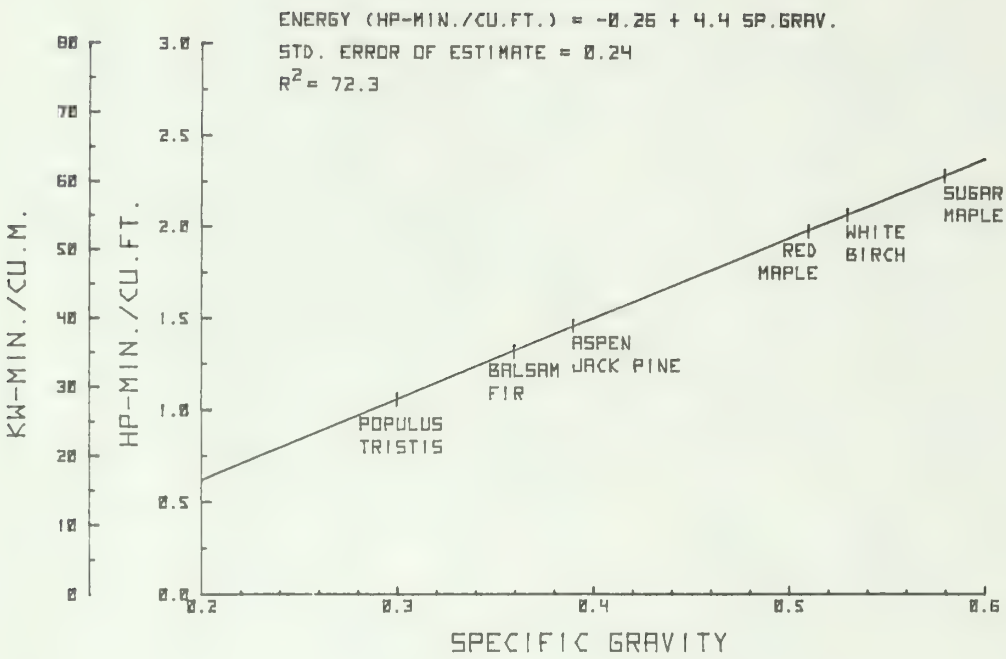

Figure 3.--Energy required to chunk several Lake States' species.

BIOMASS FROM INTENSIVELY CULTURED PLANTATIONS AS AN ENERGY, CHEMICAL, AND NUTRITIONAL FEEDSTOCK[1]

John E. Phelps[2]

Abstract.--Several technologies are described that have been developed to convert wood to fuel, chemicals or food products. Biomass from intensively cultured plantations has potential as a source of material for these energy related technologies. The technologies discussed here include: pyrolysis, gasification, liquefaction, hydrolysis, chemicals from lignin and hemicelluloses, and conversion of wood and foliage to ruminant animal feedstocks. Although these technologies show great promise, most need to become more economically attractive before they can be used on a large scale.

INTRODUCTION

One of the most pressing problems of our century is that of producing enough energy to maintain our current standard of living. Many reports indicate that we could run short of inexpensive, easily obtainable, and easily transportable energy in the near future. In fact, the first two concerns are already being realized.

During the past 50 to 100 years most of our energy needs have been met using petroleum-derived products. Before that, coal supplied much of the energy for our industrial revolution, and before coal, wood was used for many centuries. Wood and charcoal still supply much of the energy needs of the people in many developing countries (King 1980). However, the recent industrial development of the technologically advanced countries has centered around petroleum and petrochemicals and the products derived from them. Shrinking domestic supplies and concern over the ability to obtain petroleum from other countries have added to the uncertainty in obtaining needed energy sources.

Although there are no easy solutions to the energy problem, several ways have been proposed to alleviate some of the difficulties. These include: 1) conservation of resources; 2) recycling certain materials (e.g. aluminum and paper); 3) development of more fuel efficient vehicles and industrial methods; and 4) developing alternative sources of energy (e.g. nuclear, biomass, solar, wind, etc.). In addition, novel ways of using our resources have been developed. These include: 1) renovating old technologies (i.e. windmills, ethyl alcohol production from biomass, improving home designs, etc.) and; 2) developing new technologies (i.e. solar panels, deriving hydrogen from water, etc.) to reduce our energy dependence on traditional sources.

Biomass grown in intensively cultured plantations is a potential source of raw material for some of the developing energy technologies. Short rotation, intensive culture (SRIC) systems are designed to capitalize on the rapid growth potential of selected woody species by using near optimal growing conditions (Dawson 1979). SRIC plantations could be located in close proximity to industrial firms. At the Rhinelander Forestry Sciences Laboratory, we have examined the raw material quality of and certain products made from SRIC biomass in an attempt to determine product suitabilities. Our studies to date on more conventional wood and wood fiber products have produced encouraging results.

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This paper focuses on several ways of using biomass (potentially from SRIC plantations) to produce fuels and chemicals so that substitutes for petroleum based fuels and chemicals may be found. In addition, research at Rhinelander and elsewhere on substituting wood and foliage for traditional animal feedstocks will be described. Although the conversion technologies described here are somewhat general, in that they apply to most lignocellulosic (or higher plant) material or residues, it is assumed that SRIC material will behave in a similar manner.

Producing fuels and chemicals from biomass combines old and new technologies. For example, as mentioned before, ethyl alcohol production as a fermentation product from plant material has been practiced for many years. Newer technologies are directed toward developing more efficient and less costly means of producing chemicals like ethyl alcohol from plant biomass.

The conversion technologies discussed in this paper include: 1) pyrolysis - the conversion of wood to produce charcoal, liquids and gases; 2) gasification - the production of gases and subsequently methyl alcohol via combustion; 3) liquefaction - the production of higher hydrocarbon liquids (oils); 4) the production of ethyl alcohol via hydrolysis; 5) the production of other chemicals for the chemical industries; and 6) the production of animal feedstocks from wood and foliage.

PYROLYSIS AND GASIFICATION

Pyrolysis and gasification are part of the continuum of the thermal combustion process (Soltes and Elder 1981). Pyrolysis (destructive distillation) is conducted at temperatures below 600°C, in the absence of oxygen (Brink 1976), and yields charcoal and a volatile phase (Goldstein 1980). The charcoal produced by this method is a home fuel source in many developing countries, a major source of recreational cooking fuel in the United States, and is used as a coking medium in steel manufacturing in Brazil. The volatile phase can be separated into condensible liquids (pyrolignous acid, wood tars, acetone, acetic acid, and methyl alcohol) and several noncondensible gases (carbon dioxide, carbon monoxide, hydrogen and methane) (Goldstein 1980). However, gas yields from pyrolysis are not as high as those obtained during gasification. Large amounts of methyl alcohol (or wood alcohol) and acetic acid were derived from the pyrolysis process during the early part of this century (Goheen 1981). Recent studies show that vacuum pyrolysis of wood at reduced pressures (300 to 400 mm Hg) may be an economical way of producing wood oils. These oils would then be upgraded to chemicals by extraction and/or processing, while the char could be used for fuel for gasification or direct combustion (Anon. 1982).

Gasification of biomass is done at higher temperatures than pyrolysis (over 600°C) in the presence of oxygen (Brink 1976). The compounds that are formed during gasification are primarily carbon monoxide and hydrogen (called producer gas), but other gases, such as carbon dioxide, methane, and water vapor are also produced (Brink 1981, Goldstein 1980). Producer gas (gasogen, or low Btu-gas) can be burned as is (e.g. in "wood-powered" vehicles) or it can be upgraded to a synthesis gas (containing only carbon monoxide and hydrogen) and then converted to ammonia, methyl alcohol or methane. The production of methyl alcohol via the gasification process has been considered to be one of the more promising methods of producing chemicals from biomass (Reed 1980, Williams 1980). According to Reed (1980), methanol can be formed by compressing synthesis gas to 50-200 atmospheres and passing it over a chromium or copper oxide catalyst at 250 to 350°C. Methanol can either be used as an octane enhancer to produce high-octane gasoline (Goldstein 1980, Lee et al. 1980), as a gasoline extender in mixture with petroleum, as a stand alone fuel, or used to produce methane for heating fuel. The Ford Motor Company is testing methanol as an automotive fuel in 40 of their cars and they have observed no apparent technical or conversion problems (Annon. 1981a). However, the primary detrimental aspect of using methanol as an automotive fuel is that it is corrosive to some engine parts (Ofoli and Stout 1980, Williams 1980).

Methanol is also currently used in the production of formaldehyde, solvents, acrylics, insecticides, fungicides, and textile fibers (Rowell and Hokanson 1979). It can be used to produce methane using catalytic convertors operating at high pressures (Rowell and Hokanson 1979). This process, however, is quite energy intensive and requires further technological development to be economically feasible (Cheremisinoff 1980).

LIQUEFACTION

Liquefaction is the thermochemical conversion of biomass to fuel oils. As mentioned earlier, methanol can be produced from synthesis gas. Methanol can then be converted to oil

using the Fisher-Tropsch (Goldstein 1980) or the Mobil processes (Lee et al. 1980). This approach is called "indirect" liquefaction (Reed 1980).

In most cases, however, liquefaction refers to the production of fuel oil (also known as heavy oil, "proto-oil", or "protoproduct") directly from plant biomass. Although Berl (1944) was primarily describing work on non-woody plants, he indicated that "protoproduct" (with a higher heating value of 14000-15000 Btu per pound) can be derived from any carbohydrate containing material. This "protoproduct" could be used as a substitute for fuel oil or, following treatment, as diesel fuel.

More recently, Appell (1977), Boocock and Mackay (1980), Cheremisinoff (1980), Reed (1980), Miller and Fellows (1981), Petter et al. (1981), and Livingston (1982) have studied liquefaction with encouraging results. In those studies, the wood was ground-up or shredded, mixed with water, and converted to oil using a catalyst (nickel or sodium carbonate), elevated temperatures (250 to 400°C), elevated pressures (1500 to 3500 psig), and an atmosphere rich in carbon monoxide (CO). Apparently the CO removed part of the oxygen from the wood carbohydrates. The oil produced had a Btu content of 13000 to 17000 Btu per pound (Appell 1977), compared to wood with a Btu content of about 8500 Btu per pound and heating oil with a Btu content of 18000 Btu per pound (Livingston 1982). Pepper et al. (1981) and Livingston (1982) published reports on the liquefaction of aspen while Boocock and Mackay (1980) published on the liquefaction of fast growing hybrid poplar trees. All studies obtained good results; e.g. Livingston (1982) reported a 35% to 45% conversion of the dry wood mass to oil. This recovery is equivalent to approximately one to two barrels of oil from each ton of wood. Unfortunately, production costs of $50.00 a barrel must be reduced considerably for the liquefaction process to be economically feasible at the present price of oil.

HYDROLYSIS

Pyrolysis and gasification processes are, by nature, rather non-selective processes for the conversion of wood to chemicals (Goldstein 1981a) in that the whole woody biomass is reduced in a single step. Processes such as hydrolysis are more selective in that the wood is separated into its three main components -- cellulose, hemicelluloses, and lignin during processing. Each component is, in turn, converted to useful chemicals (Goldstein 1981a), energy, and food (Lora and Wayman 1979).

One method that has been proposed for the separation procedure involves two steps (Seaman 1980, Lyons 1981). In the first step, hemicelluloses are removed using a dilute acid, warm alkali or steam pretreatment and the lignin is removed by solvents (e.g. cadoxen) (Lyons 1981). Cadoxen has also been shown to disrupt the crystalline structure to cellulose and make it more susceptible to hydrolysis (Ladisch et al. 1978). In the second step, the cellulose is hydrolyzed by either enzymes or acids. Hemicelluloses, if left in the solution, produce pentose sugars and acetic acid which interfere with product purity (Lyons 1981) and inhibit fermentation of sugars to ethanol (Cheremisinoff 1980). In addition, pretreatment enhances the susceptibility of the cellulose to further hydrolysis by either chemicals or enzymes (Zerbe 1980).

Other advantages of pretreatment are: 1) acceptable sugar yields (48% to 50%) and a high concentration of sugar (10% to 12%) can be obtained; 2) pentoses can be derived in the first stage and glucose in the second; 3) steam can be used or if acids are used, there is a low consumption of the acid; and 4) small digestors can be used due to the short time of hydrolyzation (Saeman 1980). Apparently the use of a steam pretreatment is species dependent because Lyons (1981) observed that steam pretreatment rendered poplar wood more susceptible to enzyme activity, but softwoods were rendered less susceptible.

Hydrolysis is the selective conversion of the carbohydrate components of wood to their constituent sugars (Goldstein 1980). It can be accomplished via several different methods. Autohydrolysis is actually a specialized form of pretreatment in that high pressure steam or a steam explosion process is used to separate hemicelluloses and lignin from cellulose. Hanselmann (1982) considered steam explosion of wood to be a very efficient separation process. Steam explosion yields cellulose, hemicelluloses that are partially hydrolyzed, and low molecular weight lignin compounds. The cellulose can then be digested by microorganisms to form ethanol (Hanselmann 1982). The hemicelluloses can be further processed to make furfural and xylitol, fermented to alcohol via microorganisms (Williams 1980), or used as a substrate for yeast production (Saeman 1980). The lignin that is obtained by this process is in a highly reactive form that can be extracted under relatively mild conditions (Lora and Wayman 1979).

Acid hydrolysis has been used successfully since the turn of the century. This process gained considerable attention during the World Wars when sources of petroleum were

under siege. Following W. W. II, interest in acid hydrolysis declined but interest has been renewed in the 1970's due to escalating oil prices.

In the acid hydrolysis process, either hydrochloric or sulfuric acid is used. Hydrochloric acid is used in concentrated form while sulfuric acid can be used in either dilute or concentrated forms. Concentrated acids allow hydrolysis to be conducted at lower temperatures than dilute acids and they give higher yields. However, concentrated acids require expensive, non-corrosive equipment and higher costs for acid recovery systems (Goldstein 1981a). Dilute acid hydrolysis is less corrosive but gives lower yields and requires higher operating temperatures (Goldstein 1981a). In addition, although lignin has little effect on acid hydrolysis (Saeman 1979, Goldstein 1980), it is often rendered insoluble and unreactive following acid hydrolysis (Lora and Wayman 1979). Acid hydrolysis is one of the older technologies for converting biomass to various chemicals (Bungay 1982) and has the advantage of being applicable to most species of wood.

Enzyme hydrolysis is a third method for reducing cellulose to glucose and subsequently to ethyl alcohol. The enzymes (cellulases) for this process are derived from improved strains of wood decaying fungi and bacteria. Fungal enzymes have shown much promise in this reduction process. One of the fungi most suitable for large scale conversion of cellulose to glucose is *Trichoderma reesei*, a mutant of *T. virida* (Goldstein 1981a). Another organism that produces enzymes to convert cellulose to glucose is *Aspergillus* (Lyons 1981). Some organisms that hydrolyze glucose to ethanol include a yeast of *Saccharomyces* (Wiegel 1982) and bacteria of *Clostridium* (Wiegel 1982) and *Thermonospora* spp. The yeast, *Pachysolen tannophilus*, directly converts xylose (from hemicelluloses) to ethanol (Anon. 1981b). Another yeast, *Candida tropicalis*, converts xylose to ethanol under aerobic conditions (Jeffries 1981).

Although enzyme hydrolysis has been shown to give higher yields of glucose than acid hydrolysis (Lyons 1981), there are several problems inherent in its use. Research is now focusing on solutions to these problems. One problem is that most enzymes function best in a rather narrow temperature range. Enzymes are also negatively influenced by the high degree of crystallinity of cellulose and the high lignin content usually found in wood (Goldstein 1980). At present, the costs of these enzymes is also prohibitive, but these costs are declining and they may be more attractive in the future (Bungay 1982). In addition, the reaction time for the enzyme hydrolysis process is much slower than acid hydrolysis (Goldstein 1981a).

Glucose derived from hydrolysis can be converted to ethyl alcohol via fermentation (Lyons 1981), and ethyl alcohol can be converted to ethylene or butadiene, both important industrial chemicals (Goldstein 1980). Glucose can also be converted to a food that may be consumed by man or animals; to a feedstock to make solvents, plastics or other chemicals currently made from petroleum; or converted to single cell protein to be used as a food supplement (Lyons 1981).

OTHER CHEMICALS FROM BIOMASS

All chemicals in the wood should be fully utilized to make chemical utilization of wood economically feasible (Goldstein 1975). The best way to do this, as discussed above, is to separate the wood into its three main chemical components -- cellulose, hemicelluloses, and lignin, and make products from each component. The utilization of cellulose, via hydrolysis, has already been discussed. Although cellulose can be useful in producing materials such as glucose, single cell protein, etc., possibly its major benefit will come in the production of ethyl alcohol. Ethyl alcohol is currently being used as a motor fuel in Brazil and in some states in the United States. Ethyl alcohol is also an important intermediate to industrial chemicals, primarily ethylene and butadiene as mentioned above (Goldstein 1981a). Ethylene, butadiene, and phenol (from lignin) are the major building blocks for the production of synthetic polymers (Goldstein 1975).

Other chemicals can also be derived from hemicelluloses and lignin. According to Thompson (1981), hardwoods are composed of approximately 24% lignin, 48% cellulose, 3% glucomannan and 22% xylan with approximately 3% miscellaneous polymeric compounds. However, softwoods have a slightly different chemical composition with 29% lignin, 43% cellulose, 17% glucomannan, 8% xylan, and, again, 3% miscellaneous polymeric compounds. Xylan and glucomannan are two of the most important hemicelluloses in wood. Note that the relative proportions of each are reversed in hardwoods and softwoods. Aspen and hybrid poplar have been shown to have lower lignin contents than those hardwoods described above. Aspen has a lignin content of 16% to 21% (Dickson et al.

1974, Panshin and de Zeeuw 1980, Hajny 1981) while Populus hybrids have been shown to have an average lignin content of 21% (Dickson et al. 1974).

Chemicals derived from xylose, the hydrolyzate of xylan, include: D-xylose - useful for making food additives, detergents, or polyurethane; xylitol - useful as a sweetner, humectant, and plastic plasticizer; and furfural - useful in plastics, solvents and other chemical products (Thompson 1981). However, demand for mannose-derived chemicals, the hydrolyzate of glucomannan, is currently low and will remain low unless their price becomes more competitive with corresponding glucose-derived chemicals (Thompson 1981).

Phenols and other aromatic compounds can be derived from lignin and then used in synthetic polymer chemistry (Goldstein 1975). These aromatic compounds are of particular commercial interest because of their high market value (Hanselmann 1982). In addition, vanillin is routinely obtained from lignin sulfonates in spent sulfite liquors via alkaline hydrolysis with lime and sodium carbonate under carefully controlled partial pressures of oxygen (Goheen 1981). Vanillin is used for food flavorings and in the perfume industries (Goheen 1981). Unfortunately, if all hemicelluloses were converted to furfural and all lignin to phenols, the chemical market may not, at the present time, be able to absorb the large quantities obtained (Goldstein 1981b). Therefore, new markets for furfural and phenol will have to be developed.

ANIMAL FEEDSTOCKS FROM WOOD AND FOLIAGE

Although wood is made up of carbohydrate material, carbohydrates are often inaccessible to organisms that can reduce them into readily usable forms of energy. As mentioned earlier, the major reasons for this are the high degree of crystallinity of the cellulose and the high amounts of lignin present in wood. The presence of lignin in wood has been particularly effective in reducing the digestibility of wood to ruminant microorganisms (Hajny 1981, Scott et al. 1969).

Most work to date on this topic has been concerned with digestibility trials using ruminant animals. These animals require large amounts of vegetable matter in their diets. Research is aimed at supplementing their diets with wood feedstocks to extend the grain resource base.

Wood can either be used as a roughage (non-nutritive) material or as an energy food for ruminant animals (Scott et al. 1969). Use of highly concentrated cattle feeds require the addition of certain amounts of roughage so that the animal can maintain good health. Baker et al. (1975) considered 5 to 15% screened sawdust to be a practical roughage quantity in beef cattle rations.

However, the use of wood as an energy food for ruminants requires that wood be rendered more digestible. Because there is a direct relationship between the in vitro digestibility of wood and the degree of lignification (Hajny 1981), delignification of woody biomass is essential for improving digestibility. Populus wood has been shown, in some cases, to be relatively digestible without delignification, presumably because of its low lignin content (Kamstra 1979). However, delignification processes have been shown to improve the digestibility of Populus wood as well (Mellenberger et al. 1971).

Hajny (1981) and Satter et al. (1981) described several methods to increase the digestibility of wood. These include: electron radiation; vibratory ball milling; treatment with anhydrous ammonia, gaseous sulfur dioxide, or dilute sodium hydroxide; and use of pulping residues. Electron radiation, vibratory ball milling, and treatment with anhydrous ammonia, or dilute sodium hydroxide have been shown to increase the digestibility of hardwoods, but have little effect on the digestibility of softwoods (Hajny 1981, Satter et al. 1981). However, the use of gaseous sulfur dioxide does not exhibit this species specificity. The use of pulp residues will vary depending on the species and the pulping processes used. In general, screen rejects and pulp fines have acceptable digestibilities for ruminants (Hajny 1981).

All methods, in one way or another, influence biomass digestibility to varying degrees and have varying costs associated with them. From the standpoint of SRIC material, however, the results of digestibility trials of aspen are encouraging. Populus hybrids would probably behave similarly.

Autohydrolysis has been quite successful in the defibration of low density hardwoods (i.e. aspen). An autohydrolysis process developed by STAKE Technology Ltd. has shown particular industrial potential for the production of cattle feed supplements from the cellulose of native aspen.

The use of wood feedstocks also requires the addition of protein and other nutrients (Satter et al. 1981) before they would become an acceptable dietary supplement. In addition, the preparation of animal feedstocks from wood may require cost reductions to be competitive.

Although the discussion thus far has centered around uses of woody material as a fuel, energy or nutritional material, another possible product from SRIC plantations is commercial foliage.

An analysis of the chemical composition of hand-picked foliage from Populus hybrid clones indicated that this material was high in protein and could be used as a high quality livestock feed supplement (Dickson and Larson 1977a, 1977b). As a result of these analyses, further research has been devoted to the mechanical separation of leaves and commercial foliage from hybrid poplar trees.

Two methods that have been examined to date are the Morbark commercial foliage separator and the vacuum airlift segregator (VAS) (Crist et al. 1979, Isebrands et al. 1979, Nelson 1982[3]). The VAS has vacuum settings which can be adjusted to separate wood, bark, and leaf material that is riding on a wire mesh conveyor belt. The VAS was developed by the Forestry Sciences Laboratory at Houghton, Michigan (Arola et al. 1976, Sturos 1978, Sturos and Dickson 1980). Digestibility trials of VAS separated commercial foliage have shown particular promise (Crist et al. 1979) especially when the VAS is adjusted for maximum leaf separation (Nelson 1982[3]). In addition to high digestibilities, the VAS commercial foliage is high in protein and could possibly be used as a low-cost protein supplement in ruminant animals (Nelson 1982[3]). Further analyses are being done, and the results are encouraging.

SUMMARY

Woody biomass and woody residues offer much potential as a source of material for fuel, chemical and nutritional feedstocks. These raw materials are readily available in large quantities in this country, they are renewable, and in the case of intensively cultured plantations, they can be cultivated in areas close to where they are needed to provide maximum return.

A great deal of research has been done on the technological aspects of converting biomass to these energy and food related products. Apparently many of the technical problems have been solved. However, what is currently needed are ways to make these technologies more economically attractive. Biomass grown in intensively cultured plantations offers a new and attractive source of material for these promising technologies.

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ECONOMIC INVESTIGATIONS OF SHORT ROTATION INTENSIVELY CULTURED HYBRID POPLARS

David C. Lothner[1/]

Abstract.--The history of the economic analyses is summarized for short rotation intensively cultured hybrid poplar at the North Central Forest Experiment Station. Early break-even analyses with limited data indicated that at a price of $25-30 per dry ton for fiber and low to medium production costs, several systems looked profitable. Later cash flow analyses indicated that two systems without irrigation and fertilization could achieve internal rates of return of 8 percent with a 5 percent inflation rate. However, two systems with irrigation and fertilization had negative internal rates of return. All systems had negative net present values when a 10 percent discount rate was used. We are currently incorporating risk analysis into our financial investigation to directly account for uncertainty in the performance calculations.

During the last several years interest has increased remarkably in intensive agronomic techniques to produce high yields of woody biomass for energy and fiber. And our knowledge and experience through many studies and field trials has been increasingly encouraging. Land managers and scientists in both the public and private sectors are facing several important decisions.

For the land manager few tasks are more challenging than developing a production plan to meet future mill requirements. Options include: investing in intensive culture short-rotation (SRIC) forest plantations, investing in conventional less-intensive longer rotation forest plantations, or purchasing the wood as needed on the open market. If a decision is made to invest in SRIC forest plantations, how intensively should these plantations be managed and which of numerous management perscriptions should be followed?

For the scientist it takes time to develop information about specific management alternatives and the number of possible management alternatives is enormous. Scientists must decide which aspects--site preparation, planting, post-planting release, etc.--of the overall management system merit further study in order to improve performance.

The economist can aid both. He can aid the manager with financial analysis models that describe cost and return relations, determine capital requirements, and calculate financial performances of alternative projects. He can aid both manager and scientist by pointing out the importance of the various activities to the overall financial performance. And, finally, he can suggest the most fruitful areas for future research from a financial perspective.

In this paper I will summarize past intensive culture economic research sponsored by the North Central Station, discuss present ongoing work, and make some general conclusions.

BREAK-EVEN ANALYSIS

When early research efforts began, SRIC systems were believed to have several advantages over conventional silviculture systems. SRIC systems could produce more biomass from the same acreage or the same quantity of biomass from less acreage. SRIC systems could also produce this biomass much sooner--5 to 15 years after establishment rather than the 30 to 80 years of conventional silviculture. Finally, the plantations could be regenerated by coppicing every 5 to 10 years from the same root stock, thus eliminating the need for periodic replanting.

A major disadvantage was that SRIC systems require large capital expenditures for higher quality, accessible land as well as for all the

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machines and installations required to perform the intensive management. This is particularly true for irrigated plantations.

Thus, the economic potential of alternative SRIC systems generated much discussion as the research program began and break-even analysis was selected to make preliminary economic evaluations (Rose 1976, Rose and Kallstrom 1976, and Rose 1977). With break even analysis, the compounded cost of growing and harvesting biomass is calculated under alternative management strategies. This in turn is compared to: (1) the physical yield (e.g., dry tons/acre/year) at a specified price, or (2) the price (e.g., dollars/dry ton) at a specified physical yield. The break-even point is the dollar value of the yield that just covers all compounded production costs.

Several different production systems were evaluated using this technique. The major variables were spacing, rotation length, number of coppices, cultural practices (e.g., replanting), and project length (table 1). Estimating production cost is extremely important in a break-even analysis. However, little actual data were available when the early analyses began, complicating the situation. Thus, each of the production systems was evaluated under low, medium, and high cost assumptions for two different initial site conditions: forest and pasture.

These early break-even results estimating the cost per dry ton of fiber produced are shown in table 2. Alternatives 5, 6, 7, 8, and 10 would be profitable assuming both a price of $25-$30 per ton for dry fiber and production costs at a low to medium level. Alternative 3 would be profitable only when the same prices are assumed and costs are low.

Table 1.--Specifications for intensive cultural alternatives

Alternative	Spacing (feet)	Rotations (number/ years)	Stand Origin	Project Length (years)	Regeneration Planting (age)
1	4x4	(1) 4 (4) 4	cuttings coppice	20	none
2	4x4	(2) 4 (2) 4	cuttings coppice	24	13
3	4x4	(1) 5 (3) 5	cuttings coppice	20	none
4	2x4	(2) 2 (4) 2	cuttings coppice	20	11
5	12x12	(1) 10 (1) 10	cuttings coppice	20	none
6	12x12	(2) 10	cuttings	20	11
7	12x12	(1) 15 (1) 15	cuttings coppice	30	none
8	4x4	(1) 15 (1) 15	cuttings coppice	30	none
9	4x4	(1) 5 (3) 5	cuttings coppice	20	none
10	12x12	(1) 15	cuttings	15	none

Table 2.--Break-even results of ten intensive culture alternatives

Alternative	Initial Site Condition	Cost Range/Ton of Fiber Produced (low) (high)
1	Forest	$ 53.48-$ 97.21
	Pasture	43.82- 84.71
2	Forest	54.89- 100.59
	Pasture	45.73- 68.75
3	Forest	29.82- 58.74
	Pasture	24.26- 51.56
4	Forest	512.78- 739.46
	Pasture	436.54- 652.02
5	Forest	21.68- 44.88
	Pasture	17.30- 39.18
6	Forest	22.23- 45.58
	Pasture	17.82- 39.88
7	Forest	27.11
	Pasture	22.65
8	Forest	26.86
	Pasture	22.67
9	-------	35.34- 60.64
10	-------	18.23- 42.08

Production cost per dry ton differs greatly depending upon the general cost level assumed. Also, these production costs were calculated from harvest yield assumptions based on experimental plots that were irrigated and fertilized annually (Ek and Dawson 1976). In contrast, most of the alternatives shown in table 2 assumed no irrigation and only periodic fertilization. If the management alternatives were carried out on sites where water and nutrients were limiting factors, the costs would be higher. Thus, these first analyses were crude and only roughly approximated the economic potentials of alternative production systems. Further investigations would be necessary using more sophisticated models when better production cost and yield information became available.

CASH FLOW ANALYSIS

As research on SRIC progressed, more realistic information became available on production costs and biological growth and yield, and land managers wanted more specific economic information about short-rotation systems, we chose to analyze them with a cash flow model (Lothner et al. 1981, Rose et al. 1981, and Ferguson et al. 1981).

We evaluated a few specific hybrid poplar plantations representing a likely range of spacings (4 by 4 feet and 8 by 8 feet), rotations (5, 10 and 15 years), and cultural practices (including irrigation and fertilization). Four alternative systems combined these variables (table 3). Each system consisted of 1,000 acres of cleared marginal agricultural land arranged in 10 tracts of 80 to 120 acres each.

Table 3.--Four alternative SRIC systems

	Rotations		Dry Yields	
Alternatives	Length	Stand Origin	Per Acre/ Year	Total Yield at End of Rotation
	(years)		(tons)	(tons)
4 by 4 foot spacing irrigated and fertilized	10	cuttings	6.3	63
	5	coppice	7.2	36
	5	coppice	7.2	36
	5	coppice	7.2	36
	5	coppice	7.2	36
4 by 4 foot spacing not irrigated or fertilized	10	cuttings	3.2	32
	5	coppice	3.6	18
	5	coppice	3.6	18
	5	coppice	3.6	18
	5	coppice	3.6	18
8 by 8 foot spacing irrigated and fertilized	15	cuttings	6.3	95
	15	coppice	6.3	95
8 by 8 foot spacing not irrigated or fertilized	15	cuttings	3.2	47
	15	coppice	3.2	47

The important production and management activities of each system were identified by North Central scientists and the forester in charge of the only large-scale industrial SRIC plantation in the Lake States. Physical and dollar estimates were made for each of the production factors and yields as well as the relative uncertainty of each. Using a cash flow model, the financial performance of each system was evaluated by an internal rate of return (IRR) and present net value (PNV) criteria for a 30-year period. We also evaluated the sensitivity of the IRR and the PNV to both relative and absolute changes in the production factors and yields due to uncertainties.

Site preparation for the plantations included plowing, disking, and applying preplant herbicides. All these activities took place in late summer and fall prior to spring planting. Three cultivations and two applications of herbicide were used for postplanting weed control. Trees were irrigated by a traveling gun system that applied 10 inches of water per acre annually. Liquid nitrogen fertilizer was applied in the irrigation water at 100 pounds per acre per year. Plantations were harvested using whole-tree chippers for the 10- and 15-year rotations, and forage harvesters for the 5-year coppice rotations. Expenditures common to all alternatives included administrative costs, insurance, land purchase and sale, equipment cost, and taxes (income and property).

An annual inflation rate of 5 percent and a 10 percent discount rate were applied to all costs and returns.

Some of the cost and return assumptions follow:

Cost	Estimate (1979 dollars)
Land	\$400 per acre
Planting stock	\$ 80 per thousand
Fuel (diesel)	\$ 1 per gallon
Labor (nonunion)	\$ 4 to \$ 6 per hour
Site preparation & weed control	\$33.42 to \$73.11 per acre
Irrigation	\$99.74 per acre per year
Irrigation equipment	\$387,700(initial investment for 1,000 acres)
Harvest	
Whole tree	\$ 14 to \$ 18 per dry ton
Forage	\$ 8 per dry ton
Administration	\$7,500 per year (for 1000 acres)
Property tax	\$ 4 per acre per year
Income tax	28 percent of capital gains
Equipment insurance	1 percent of new price per year
Return	
Product value	\$25 per dry ton

A more detailed account of the costs and returns is found in Lothner et al. (1981) and Rose et al. (1981).

With the assumed 10 percent discount rate, no alternative had a positive PNV. However, the two systems without irrigation and fertilization had positive after tax internal rates of return of 8 percent; the two irrigated and fertilized systems had negative internal rates of return (table 4). Economically, dif-

Table 4.--Initial investment and investment performance of four SRIC alternatives

Management Alternative	Initial Investment[1] (dollar/acre)	Present Net Value (dollar/acre)	Internal Rate of Return (percent)
4 by 4 foot spacing, irrigated and fertilized, short-rotations (5 to 10 years)	1,158	-2003.82	-0.4
4 by 4 foot spacing, not irrigated or fertilized, short-rotations (5 to 10 years)	770	- 236.78	8.1
8 by 8 foot spacing, irrigated and fertilized, long-rotations (15 years)	945	-2149.51	-1.6
8 by 8 foot spacing, not irrigated or fertilized, long-rotations (15 years)	557	- 200.30	8.1

[1] Includes land purchases, initial equipment purchase or lease, site preparation and planting costs, and administration cost for first two years.

ferences were small between rotation length and spacing options, but they were significant between the systems that were irrigated and fertilized and those that were not.

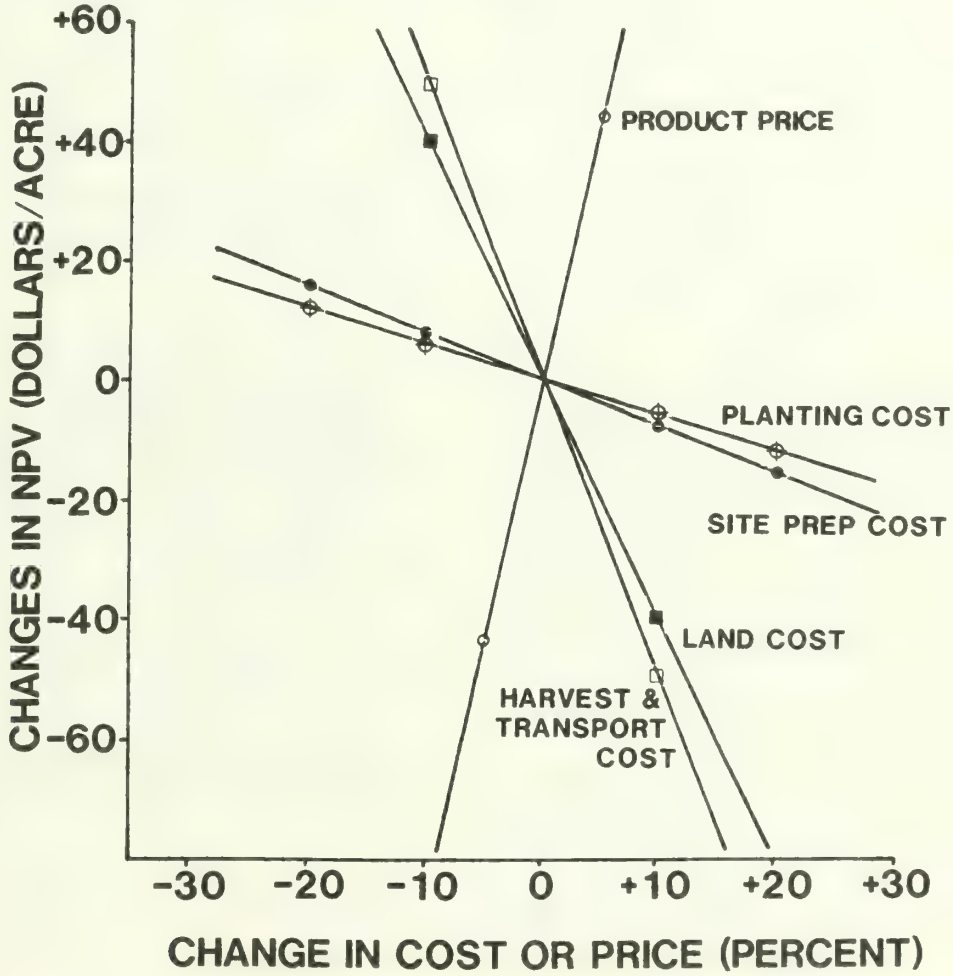
A sensitivity analysis can help identify how each cost or revenue factor affects the financial performance. In all four systems, the most important factor affecting investment performance was the product sale value. It was also one of the most uncertain factors. A change in yield, product price, or both, could substantially change the economic attractiveness of SRIC systems. For example, a 10 percent increase in mill prices from $25 to $27.50 per dry ton for chips for the 8 by 8 foot nonirrigated and nonfertilized system increased the PNV by 44 percent or $88 (fig. 1).

For systems without irrigation and fertilization, harvest and transport cost were the next important factor. For the 8 by 8 foot spacing alternative, a 10 percent change in harvesting and transport cost changed PNV by almost 25 percent or about $49 (fig. 1).

For the irrigated and fertilized systems, irrigation operating costs, primarily fuel, was the second most important factor affecting investment performance and would have to be substantially reduced for these systems to become financially attractive. Fuel costs represent 68 percent of the operating costs of the traveling gun irrigation system and a substantial fuel cost reduction with this type of irrigation system seems unlikely. However, new technology or changes in the irrigation schedule to only sporadic use (e.g., during establishment) could significantly reduce irrigation operating costs.

Site preparation costs and planting costs for any of the systems have little effect on PNV. For example, a 10 percent change in site

Figure 1.--Sensitivity of net present values (NPV) for 8 by 8 foot spacing, nonirrigated and nonfertilized system to relative changes in costs or prices.



preparation cost for the 8 by 8 foot, nonirrigated and nonfertilized system changes PNV by 4 percent or $8, while a 10 percent change in planting cost changes PNV by 3 percent or $6 (fig. 1).

The cash flow analyses suggested that nonirrigated and nonfertilized SRIC systems would be preferable to those that are irrigated and fertilized. But because the returns on investment would be low even for the nonirrigated and nonfertilized systems, these systems would be of interest only to individual users of wood biomass who can compare the potential of these systems to alternative sources of supply prior to making an investment decision.

In addition, the results indicate that the investment performance of the SRIC system is most sensitive to the product sale value (yield and product price), irrigation operating costs, and harvesting costs. Our current data concerning all these factors are inadequate. However, by pointing out their importance, we can focus our research efforts on them in the future. This may help us to reduce some of the important sources of uncertainty and make more informed future decisions. However, many of the factors depend on uncertain future events for which there will always be a limited present understanding.

However, some additional risks were not addressed by the cash flow analysis. For example, what are the risks of insect or disease outbreaks and what impact would they have on the investment performance? Or, what is the risk of failure, in unirrigated and unfertilized plantations?

RISK ANALYSIS

In a conventional cash flow analysis, mathematical formulas are used to precisely calculate financial performance estimates for various criteria by incorporating point estimates for each relevant factor included in the analysis. However, both the analyst and the decisionmaker--manager or scientist--know that behind these precise calculations are imprecise data. A great deal of uncertainty and/or risk[2/] always surrounds the basic information that goes into the analysis. Our past cash flow calculations have not adequately measured risks nor have we been able to directly incorporate risks into investment performance calculations.

[2/] In our discussions a risk situation is where the probability of an activity or event occurring is known or can be estimated; an uncertainty situation is where the probabilities of an activity or event occurring have not been estimated or determined.

We are currently cooperating with Michigan State University[3/] to model the risk inherent in SRIC projects. This work is based on some earlier work in risk analysis by Hertz (1964) and developed and reported on by others (Davidson and Cooper 1980; Economos 1968; and Hillier 1963). Incorporating risk analysis into a basic cash flow model requires three basic steps. First, a range of values is estimated for each of the production activities (e.g., a range of site preparation costs) and the probability or likelihood of occurrence of different values within the range. This is in contrast to the previous practice of estimating only the most likely value of each factor. Second, one value from the distribution of values for each factor is selected at random. The resulting set of selected values for all factors are combined in one cash flow analysis and the financial performance (e.g., internal rate of return or present net value) is calculated. Third, the second step is repeated over and over again to develop a probability distribution for the financial performance outcomes. This distribution of financial performance outcomes thus shows the probability of achieving any specified outcome--e.g., internal rate of return.

If we use two of the hypothetical SRIC systems mentioned earlier--the 4 by 4 foot and 8 by 8 foot nonirrigated and nonfertilized systems--we can illustrate what a risk model can provide in comparison to the conventional cash flow model. Let me emphasize that the numbers found in this section using the risk analysis model have no empirical value. They have been selected only to illustrate the risk analysis method.

Using a conventional cash flow model, both the 4 by 4 foot and 8 by 8 foot nonirrigated and nonfertilized alternatives show 8 percent internal rates of return. Incorporating risk estimates provides the decisionmaker with estimates of the probabilities of achieving each possible value for the financial performance criteria--e.g., internal rate of return. Let's assume that when we incorporate risk into our analysis, the most likely outcomes for both the 4 by 4 foot and 8 by 8 foot alternatives remain the same as the conventional outcome--an 8 percent internal rate of return (fig. 2). In practice the most likely internal rates of return found using a risk analysis model would probably differ from the expected internal rates of return found under the conventional method using single point estimates. In the example above, we have

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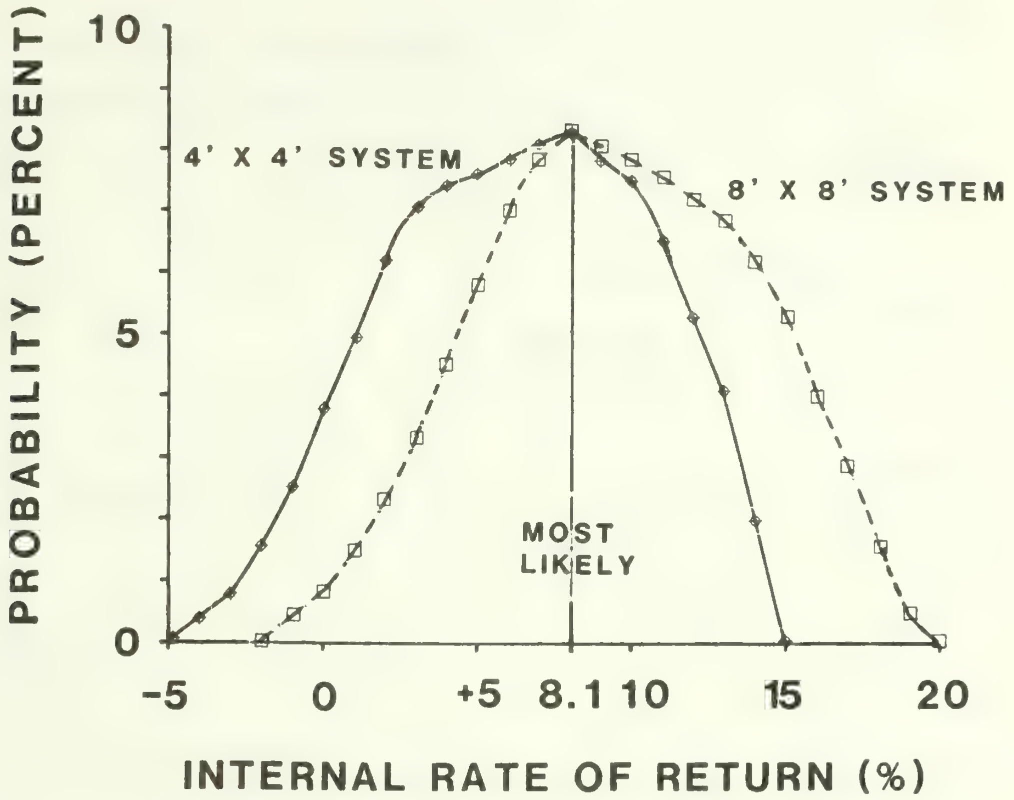
Figure 2.--Probability distributions of the internal rate of return for two hypothetical SRIC systems.



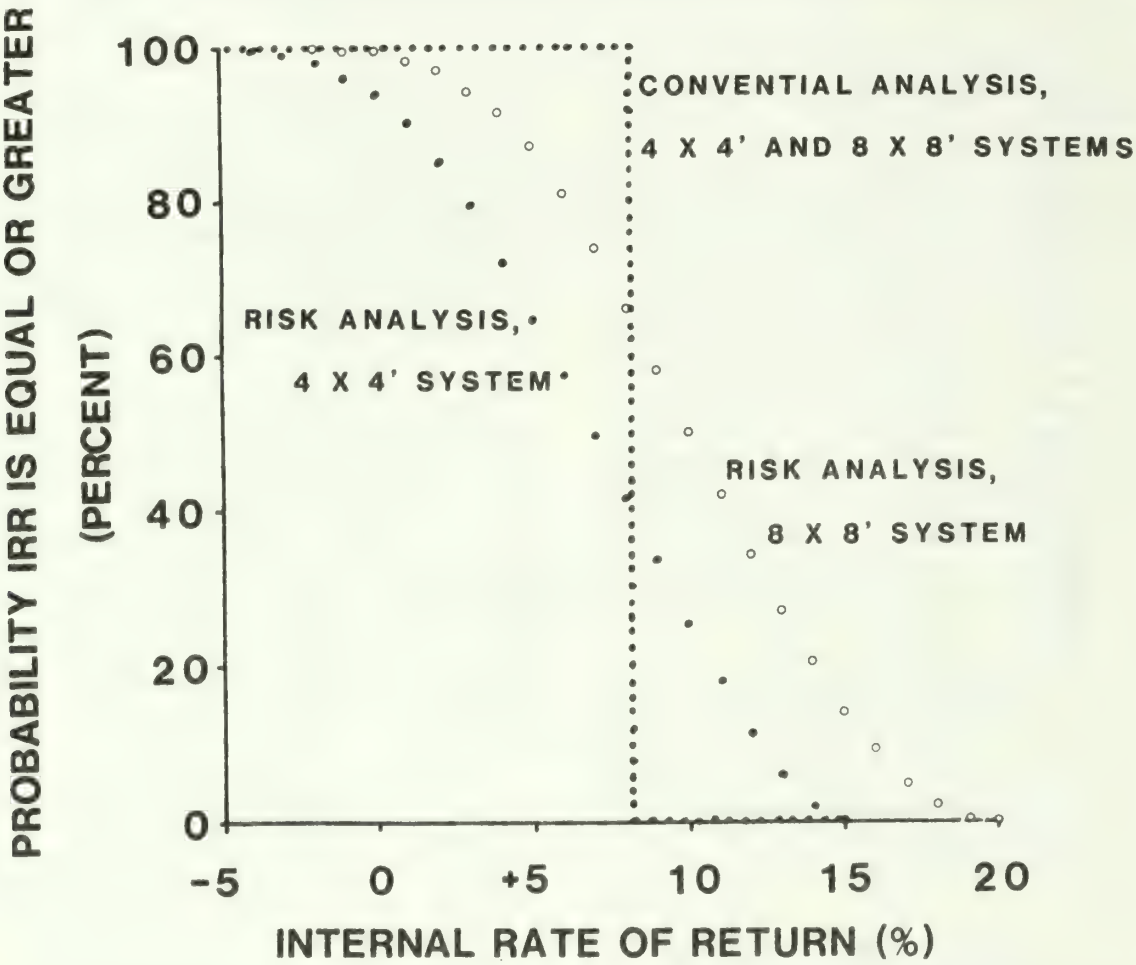
assumed both alternatives have about an 8 percent chance of achieving the 8 percent internal rate of return. The chances or probability of a zero or negative internal rate of return (no profit at all or even a loss) are much greater for the 4 by 4 foot system (fig. 2). (Remember that these numbers are for illustration purpose only and have no empirical value.)

Using a risk analysis method, the uncertainty of achieving at least a certain financial performance--i.e., internal rate of return--can be clearly displayed:

Internal Rate of Return	Probability of achieving at least the returns indicated	
Percent	Percent	
	8x8' spacing	4x4' spacing
0	99	94
2.5	96	83
5.0	87	65
7.5	69	45
8.1	66	42
10.0	50	25
12.5	29	8
15.0	14	0
17.5	3	0
20.0	0	0

We can compare the cumulative profile for the 8 by 8 foot and the 4 by 4 foot spacing systems using a risk analysis with the profile for these systems obtained under the conventional approach (fig. 3). Under the conven-

Figure 3.--Cumulative rate of return profile for two hypothetical SRIC systems using a conventional cash flow model and a risk analysis model.



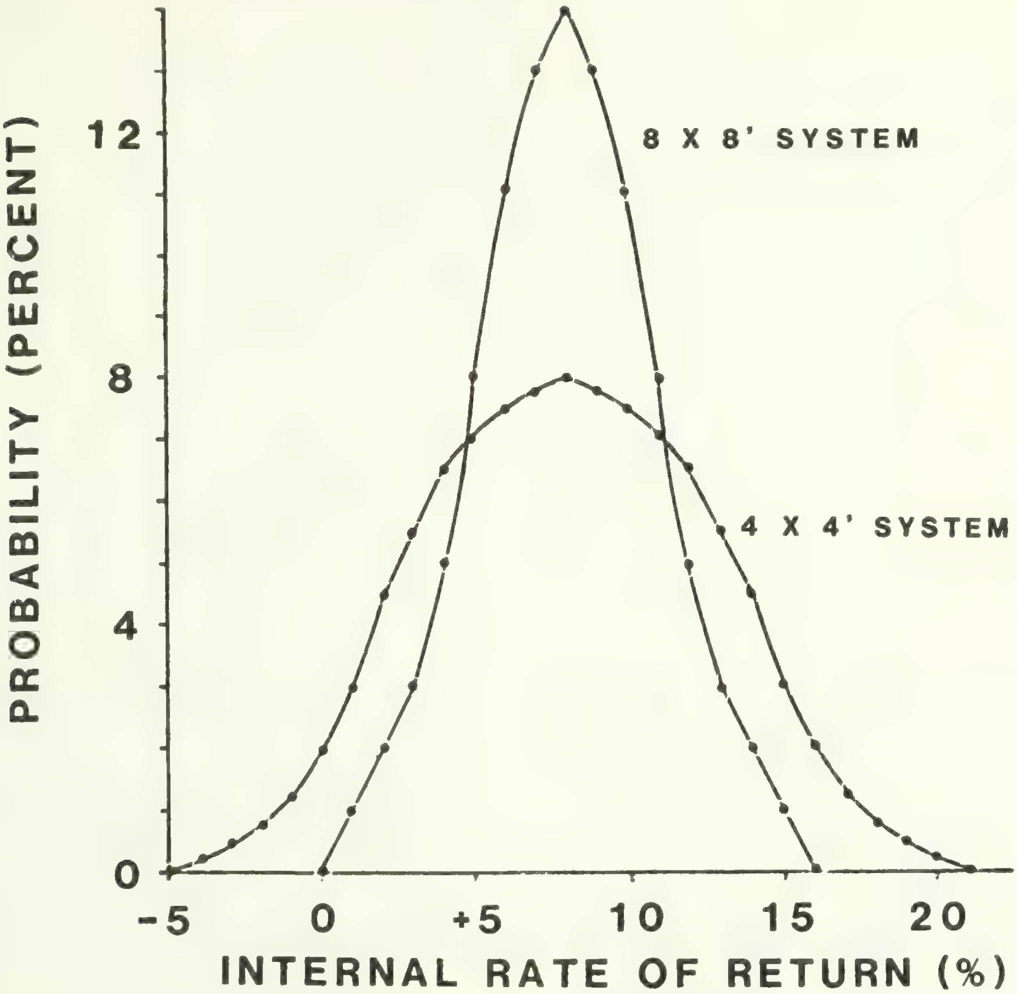
tional cash flow approach we would have no way to choose between the two systems because both produced an 8 percent internal rate of return. However, using risk analysis we can see that the 8 by 8 foot spacing would be superior to the 4 by 4 foot spacing. With the wider spacing we are 99 percent certain that we will not obtain a negative internal rate of return as compared to only a 94 percent chance with the narrower spacing alternative. In addition, we have a 66 percent probability of achieving at least an 8 percent rate of return with the wider spacing system as opposed to only a 42 percent probability with the narrower spacing. It is clear in this example that the wider spacing system is significantly better. Without accounting for risk in the model as with the conventional cash flow model, we would never know this.

This is not to say, however, that using risk analysis will always present information to the analyst for making clear choices. An analysis between two alternatives could result in one alternative being both more risky as well as having a greater opportunity for larger gains (fig. 4).

SUMMARY AND CONCLUSIONS

Economic analysis of SRIC at the North Central Forest Experiment Station has progressed during the past several years. After some early break-even analyses when basic data required for economic evaluation were almost nonexistent, we moved on to discounted cash flow analyses using sensitivity analysis to handle risks and uncertainties. Through these analyses we learned that using single estimates of production factor values, the monetary returns were fairly low. Through the sensitivity analysis we learned that financial performance was most sensitive to product price, product yields, irrigation costs, har-

Figure 4.--Alternative probability distributions of the internal rate of return for two hypothetical SRIC systems.



vesting costs, and land costs. These are all highly uncertain factors. The traditional and more certain management activities necessary to establish and grow hybrid poplars, such as site preparation and planting, were not as important as the previous factors. We also believe that considerable risk is involved in analyzing the financial performance of these systems where uncertainties are not directly accounted for within the system.

From a growing awareness of the importance of uncertainties we began to develop models to handle this problem. Work is still in progress so we do not have any real results. However, we can use hypothetical examples to show the kind of information that can be obtained by incorporating risk directly into the financial analysis.

Much work remains. If we recognize uncertainty, how do we build the model to allow managers to react to possible outcomes? And, once the model is developed, are there any real advantages for evaluating SRIC investment opportunities by this method? These will take considerable effort. Yet, the discipline of thinking through the uncertainties of the problem will perhaps in itself help the analyst assist the decisionmaker in making wise investment choices.

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FOUNDING CONCEPTS FOR TREE BREEDING AND RESEARCH

Hyun Kang[1]

Abstract.--Forestry research is a multidisciplinary venture and is typically a long-term effort with relatively low funding. The success of forestry research and tree breeding depends greatly on the coordination among forestry practitioners, research managers, and researchers. To coordinate they must have a common understanding of the research process. Therefore, the common understanding is the conceptual foundation for tree breeding and research. To develop a common understanding (1) the components of the research system must be differentiated in respect to their functions, and (2) the differentiated components must be integrated to generate the overall picture of the research system. Few general procedures are known for the differentiation and integration. Therefore, a tree breeding example was used to illustrate the differentiation and integration process, and to point out the importance of having a proper common understanding for forest tree breeding and research efforts.

To conduct meaningful research efficiently it is necessary for practitioners, research managers, and researchers to have a common understanding of the research process.[2] The common understanding will form the conceptual foundation for research activities. In the following sections I will (1) describe two views of the research process using a simple graphic model, (2) describe the components of the model using tree breeding as an example, and (3) use the model and the tree breeding example to discuss the differences between the views.

ALTERNATE VIEWS ON RESEARCH PROCESS

Different views of the research process exist because practitioners and researchers use different languages. Practitioners are concerned with practical problems and directly applicable solutions; researchers are concerned with researchable or solvable questions. I will use the term problem set (P) to represent the collection of problems defined by practitioners and solution set (S) to represent research questions and answers generated by researchers (fig. 1). Examples of problem set elements are increase biomass production, regenerate a species, and manage a plantation. Examples of solution set elements include problems in physiology, silviculture, and genetics; empirical studies; and causal analysis.

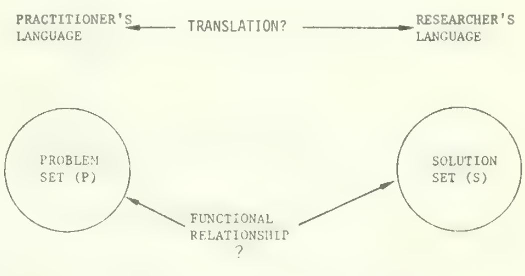

FIGURE 1. SET REPRESENTATION OF DIFFERENT LANGUAGES.

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[2]The research system represents the collection of both physical and mental components of performing research. Research organization, research personnel, research process such as problem defining and solving are some examples.

Three different phases of a research process can be identified (fig. 1): application by practitioners, research, and the translation between practitioners and researchers. These three phases must be well balanced to make good use of the research activities. However, people have different views on the way the translation phase should be handled.

In one view, the translation is considered as a temporary phenomenon that occurs as the need arises. This view is possible only when the functional relation between the two sets (P and S) is primarily additive. According to the additive functional relation, a research effort that achieves a 5 percent increase in biomass production under the experimental set-up would assure an equivalent gain in an applied operation. Therefore, by adding up the results of all other research efforts one should be able to generate much greater gain in operation. A research manager holding this view, when faced with budget reduction, could simply take out any part of the research operation without influencing the effectiveness of the rest of it (fig. 2A)

In an alternative view the translation phase is viewed as a unit that evolves. The interaction among different disciplines and research efforts is considered as a critical component of the function (fig. 2B).

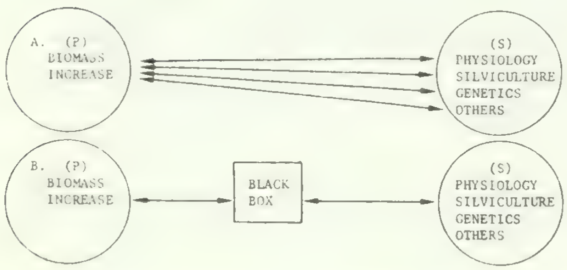

FIGURE 2. ALTERNATIVE VIEWS ON THE FUNCTIONAL RELATION BETWEEN PROBLEM SET (P) AND SOLUTION SET (S). BIOMASS INCREASE IS USED AS AN EXAMPLE.

A. ADDITIVE VIEW OF THE FUNCTIONAL RELATION BETWEEN THE TWO SETS. NO INTERACTION AMONG DIFFERENT RESEARCH DISCIPLINES IS CONSIDERED CRITICAL.

B. FUNCTIONAL LINKAGE BETWEEN THE TWO SETS THROUGH A BLACK BOX. INTERACTION AMONG DIFFERENT DISCIPLINES IS CRITICAL. TRANSLATION AND PACKAGING IS PERFORMED IN THE BLACK BOX.

Few are likely to endorse the simple additive view, but that does not necessarily mean the presence of strong efforts to improve the quality of the translation phase. The lack of effort to develop and improve the translation phase is equivalent to enforcing the additive view. Therefore, the true question is how can a good translation phase be created and improved

A firm conceptual foundation is necessary to create an evolving translation phase. The formation of the foundation takes two steps: (1) the components of the research system must be differentiated in respect to their functions-from the differentiation the members of the research system can understand the specific roles of different aspects of the system; and (2) the components must be integrated to generate the overall picture of the system. Through repeated differentiation and integration the conceptual foundation for the research will become firmer, yet remain flexible.

Few general procedures are known for the differentiation and integration. Therefore, I will use a tree breeding example to discuss the procedure and will begin by presenting a potential gain from tree breeding.

POTENTIAL GAINS FROM BREEDING

The field of genetics has advanced greatly and breeders can now predict the gain from a specific breeding technique. As a current example, a *Populus* clonal comparison study at Harshaw farm showed that selecting 1 or 7 out of 15 clones yielded 115 percent and 47 percent predicted gains in volume index (D^2H), respectively (Hansen *et. al*. 1983). The clonal selection did not include further breeding. We know from many crop and animal experiments that subsequent breeding efforts could achieve much greater gains than can be obtained in a single generation of selection. The gain in volume index could exceed 200 percent in 3 or 4 generations. This example suggests that *Populus* breeding has a great potential for increasing biomass production. Similar increase in productivity can be readily demonstrated in other tree species. No doubt breeding is an important means of increasing forest productivity. To achieve the increase in productivity of various tree species, breeders must classify the activities in the solution set by asking the following questions. First, how can such yield increases be realized? Second, can the selection process be made even more potent?

To realize the potential yield increase the environments for breeding and for operation must be relatively homogeneous and constant. The

homogeneous environment enhances the selection efficiency of a given generation, and the constant environment makes repeated directional selection possible. If the direction of selection has to change from generation to generation, recurrent selection will become meaningless and the cumulative genetic gain will never be realized.

Conventional forest tree planting sites are very heterogeneous, and two contrasting approaches to tree breeding are possible. Despite environmental heterogeneity, trees can be bred using conventional extensive cultural methods--the genetic gain will be small, but small energy inputs will be required. Or breeders can use intensive cultural efforts and minimize environmental variability--genetic gain will be greater than with extensive culture, but large energy inputs will be required.

To make the selection process more potent the selection techniques must be improved. In the above example the selection technique used was the ranking of D^2H measurements of clones. Such measurements are subject to many sources of error. Any reduction of the ranking errors would improve the potency of the selection. The error can be reduced by identifying the components that make up the trait of interest (D^2H in this example) and by understanding the functional relation between the components and the trait. This will require additional basic research on the causes of the trait response. The basic research results may or may not be directly applicable to field operation. In contrast, breeding is empirical research designed to determine the nature of responses for a given set of causes (or factors). The two research types differ depending on whether the emphasis was put on the study of the causes or on that of the responses.[2]

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[2]Definitions of basic and empirical research are, of course, arbitrary. There could be many more classes in the same classification scheme, or even completely different types of classifications. For example, contrasting basic vs applied, and theoretical vs empirical simultaneously would be more desirable in the strictest sense. A rigorous treatment of the classification, however, would require a separate discussion. In this presentation, therefore, the contrast between direct meaning of the terms, basic and empirical, is of secondary importance. It is more important to note the contrast between the meaning of the terms as they are defined here.

From the examination of the two questions four distinct elements of a solution set have been generated: extensive culture, intensive culture, basic research, and empirical research. In the following sections I will discuss the relation between breeding and extensive culture, intensive culture, and basic research. I will not discuss empirical research as an independent subject but rather I will mention it as it relates to the other elements.

BREEDING UNDER EXTENSIVE CULTURE

The justification for breeding a species depends greatly on the size of the planting program for that species. The unit genetic gain under extensive culture is small. But, because current planting is large, this small unit gain will affect a large number of planted trees and result in a large overall increase in productivity. Another requirement for breeding under extensive culture is that plantation establishment should require little cultural effort (low energy input). The foregoing two requirements limit hardwood, including Populus, breeding under extensive culture in the Lake States.

Under extensive culture the research approach is primarily empirical. Although breeders use information from basic research to determine factors to examine, the research results usually do not explain the causes of the observed responses. The research and the use of research results are also opportunistic and strategic. Instead of investigating the causes of the trait responses, breeders search for working rules that will make the breeding successful based on available information. At the same time, breeders leave room for rule changing as more information becomes available. Therefore, breeders do not strive to develop a single genotype that is superior to others on all available planting environments.

A typical breeding scenario under extensive culture begins with provenance testing--matching the available breeding stocks to different environments. From the provenance testing results, breeding and seed zones are defined. Once breeding zones are defined, breeders limit the breeding stocks in the zones and begin recurrent selections within each zone. The breeding zones reduce environmental variability which enhances the selection efficiency at the given generation. By limiting a particular set of breeding stocks within the zone while making recurrent selections the continuity of breeding environment can be maintained. Reducing environmental diversity and maintaining

continuity of the breeding environment is also used in intensive culture. In extensive culture breeding stocks are distributed to different environments, whereas in intensive culture the environment is modified to support superior breeding stocks.

Breeding under extensive culture is a logical answer to the current demand for improved plantation management technology with low energy input. The breeding effort is a reaction to the current demand. The approach is realistic because both the domain of activities and the range of the results of the activities lie within the scope defined by the current demand. In a realistic approach the success of the breeding is measured by how well the activity meets the demand. A typical result of a realistic breeding approach is the gradual and cumulative genetic gain.

BREEDING UNDER INTENSIVE CULTURE

Realistic approaches to breeding and research do not suggest revolutionary concepts that could lead to the change in the demand itself. In many cases technological breakthroughs accompany changes in the type of demand. The basic requirements for a breakthrough are imagination and futuristic views. Dawson and Hutchinson's (1973) description of intensive culture is an example. Intensive culture is the proving ground for futuristic cultural models. The most important fact that has been frequently overlooked is that futuristic approaches are usually not realistic. It is not necessary to try to justify futuristic models using realistic arguments. In all likelihood, if a futuristic model is justifiable on a realistic basis, it is no longer futuristic. Either the breakthrough already has occurred or the model was wrong. In any event, no new breakthroughs will come from the model. Dawson and Hutchinson (1973) spoke about the transition from "hunting and gathering" to domestication. Did ancient farmers begin domestication because they had economic justification? If they had tried to economically justify their activity, would modern agriculture have evolved?

The basic assumption of the futuristic intensive culture model is that once one or more economically advantageous cultural systems are developed, tree growers will use the models and divert a certain fraction of their practices to the intensive culture system.

The primary function of intensive culture is redistribution of forest land productivity. Increased productivity of certain sites may not increase overall productivity of forest land. Therefore, intensive culture can be justified with or without future timber shortage. The number of Populus trees planted annually in the Lake States or the ease of establishing Populus stands in wild environments are irrelevant to the decision to breed Populus under intensive culture. The justification should come from the growth potential, convenience for breeding and propagation, available knowledge on the species, etc.

Selection can be effective in intensive culture because the environment is relatively homogeneous and of high quality. However, the breeding still has to be strategic and breeders must be concerned about factors that influence the long-term success of breeding. For example, a well structured large breeding population(s) must be maintained.

The initial step of breeding under intensive culture is similar to that of extensive culture. For example, with Populus the program may begin with tests of clones or progenies at various locations. From the testing the breeder can match breeding stocks and sites. Using the testing materials or their progenies, breeders can select further to generate clones to be released immediately. However, the immediate release of superior clones is not an integral part of futuristic breeding under intensive culture. The futuristic breeding includes activities such as repeated selection and breeding of trees that perform better under given levels of fertilization, irrigation, and other cultural activities. The selection criteria will include many important growth components identified by the basic research. Without the futuristic breeding under intensive culture, the 200 percent gain in D^2H will not be realized. The research is primarily empirical. Even under intensive culture most breeding research does not explain the causes of the responses.

BREEDING ASSOCIATED WITH BASIC RESEARCH

Breeders cannot improve their selection and breeding techniques without supportive basic research. Under the most ideal conditions, the pool of information generated by basic researchers will be large and continuously updated and improved. Furthermore, there should be a harmony in different levels of research between very basic biological work and strategic breeding formulae. To create

such harmony requires a common ground where researchers can exchange information. Larson and Gordon (1969) have viewed intenive culture as such a common ground where technology transfer can occur between scientists.

Although the final recommendation of Larson and Gordon and Dawson and Hutchinson were the same, the emphases of the two ideas were different. Larson and Gordon emphasized the process by which the basic information can be used at higher levels of the application; it does not dictate the final destination of the information. Dawson and Hutchinson, however, emphasized generating a cultural model that maximizes return. Their approach does not discriminate the type of information used to develop the cultural model.

The breeding associated with basic research is different from breeding for production. Breeding population size in research may be small, and the number of species worked on small. In fact, for given resources it is best to generate integrated information on one or a few species. Populus is very desirable as an experimental species.

A SYNTHESIS

After studying the differences among extensive culture, intensive culture, and basic research, a tree breeder or forester may take one of the following approaches to develop an integrated view on the research system. First, he may assign economic priorities to the three categories and choose the one with highest priority (additive approach). Second, he may take all three categories and try to balance their strength (balancing approach).

A close examination of the three categories will readily show that the additive approach is difficult to accept in forestry research. For example, consider the choice between extensive culture, which is realistic, and intensive culture, which is futuristic. It is unlikely that breeders can afford to work with futuristic problems exclusively while ignoring realistic problems. Only by balancing the realistic and futuristic problems can breeders quickly respond to future trends and suggest new directions in timber management while also solving immediate problems.

The additive approach is also difficult to accept because the demands of beneficiaries of breeding and research tend to be complex. For example the tax payer may wish some immediate benefit from government research such as improved genotypes and technical assistance on managing his woodlot. At the same time he may wish the government to develop an advanced, more efficient system of producing woods while allowing room for conservation. Therefore, to satisfy the needs of tax payers, government research must include both realistic and futuristic components.

The difference between the additive and the balancing approach can be made clearer using graphics. Assume that it is possible to assign values to the research needs expressed in the problem set and research activities in the solution set such that they can be represented in a two dimensional cartesian coordinate (fig. 3). In the additive approach a one-to-one correspondence exists between points of the two sets (fig. 3B). The coordination within the solution set is not essential and the set simply represents the collection of points, and the size of the solution set is the same as that of the corresponding problem set. The main advantage of the additive approach is that individual research can be economically justified independently.

In the balancing approach the mass centers of the two sets correspond to each other (fig. 3C). Although the members of the two sets could correspond to each other, such correspondence is not the fundamental requirement. The solution set is more than a collection of points. It includes a strong structure of coordination. Because the solution set and the problem set communicate through their respective mass centers, the boundary of the solution set could be much larger than that of the problem set. In this approach, the primary unit of the economic justification is the entire research system.

When the research needs in the problem set change randomly, the corresponding points in the solution set of the additive approach must be adjusted accordingly (fig. 3D) some of the ongoing research must be discarded and some new research must be begun. No change is likely in the balancing approach because the mass center tends to remain constant under random changes (fig. 3E).

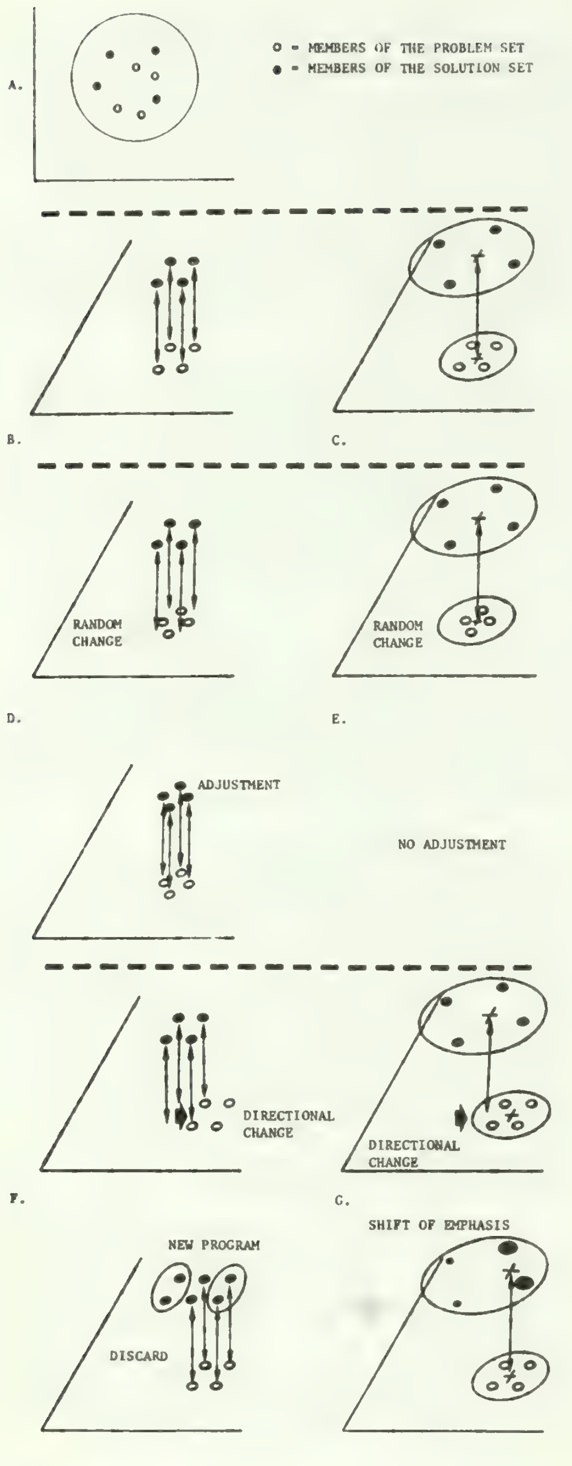

FIGURE 3. A GRAPHIC REPRESENTATION OF THE RELATION BETWEEN PROBLEM SET AND SOLUTION SET. B., D., AND F. REPRESENT ADDITIVE APPROACH, AND C., E., AND G. REPRESENT BALANCING APPROACH.

A. RESEARCH NEEDS AND RESEARCH ACTIVITIES IN CARTESIAN COORDINATES.

B. AND C. EXPLODED VIEW OF RESEARCH NEEDS AND RESEARCH ACTIVITIES. AT INITIAL STAGE RESEARCH NEEDS AND RESEARCH ACTIVITIES ARE ASSUMED TO BE WELL ALIGNED.

D. AND E. RANDOM CHANGE IN ELEMENTS OF THE PROBLEM SET.

F. AND G. DIRECTIONAL CHANGE IN ELEMENTS OF THE PROBLEM SET.

When the research needs in the problem set change directionally, adjustments are needed for both approaches. In the additive approach the same adjustments are necessary as for random changes, some projects must be discarded and new ones begun (fig. 3F). In the balancing approach the emphasis must be changed such that the mass center of the solution set can be shifted (fig. 3G). Because the boundary of the solution set is larger than that of the problem set, it is unlikely that the mass center of the problem set will move beyond the boundary of the solution set. Therefore, the problem set of the balancing approach will continue to have some immediate solutions to the new problems.

Although the balancing approach has many conceptual advantages, it is difficult to organize a solution set and align its mass center with that of the problem set. The additive approach is much easier to create and is very effective for short-term projects with abundant funding. Forestry research is basically a multidisciplinary venture with long-term efforts and low funding. Therefore, forestry researchers cannot afford to pay the price for the discontinuity associated with the additive approach.

To make the balancing approach work we must create and improve a black box, which is a vehicle for coordination (fig. 2B). Although no general procedure has been outlined for creating and improving the black box, two things are required for its successful evolution. First, researchers must have a common understanding of the research system to be used. For example, consider the Research and Development program on intensive culture. Three general areas of research will be necessary to make the program functional: (1) cultural techniques, (2) physiology, and (3) breeding. In the past, the program lacked breeding efforts but in the future, the success of the program cannot be guaranteed without it. In fact, the balancing of the three different areas of research is the key to the future success in the Research and Development program. Second, forestry practitioners, research managers, and researchers must be willing to cooperate to make the research system work. Every research system will always have some deficiencies but the deficiencies cannot be the excuse for lack of cooperation. For example, the Research and Development program still lacks a breeding program and will lack physiology research on growth characteristics of Populus but that should not prevent geneticists and physiologists from contributing to the program. Furthermore, research administrators must continue their efforts to balance the program.

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It may be helpful to think of the evolution of coordination in terms of the group selection concept in organic evolution. At the individual level, the traditional Darwinian concept of fitness works. In group selection, however, altruistic members of the group are equally important as the fittest members of the group to enhance the average fitness of the group under the given environment. If a research group becomes incoherent due to lack of coordinates and altruism, an excellent piece of research will be lost in a bag of unfit information.

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Intensive plantation culture: 12 years research. Gen. Tech. Rep. NC-91. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 155 p.

A collection of papers summarize the status of knowledge for growing hybrid poplars in a short rotation intensively cultured system. The research included studies of propagation, physiology, culture, engineering, insects and diseases, and economics.

KEY WORDS: Short rotation, energy plantations, *Populus* spp., *Alnus* spp.

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A Thermal Comparison Among Several Beverage Can Solar Collectors

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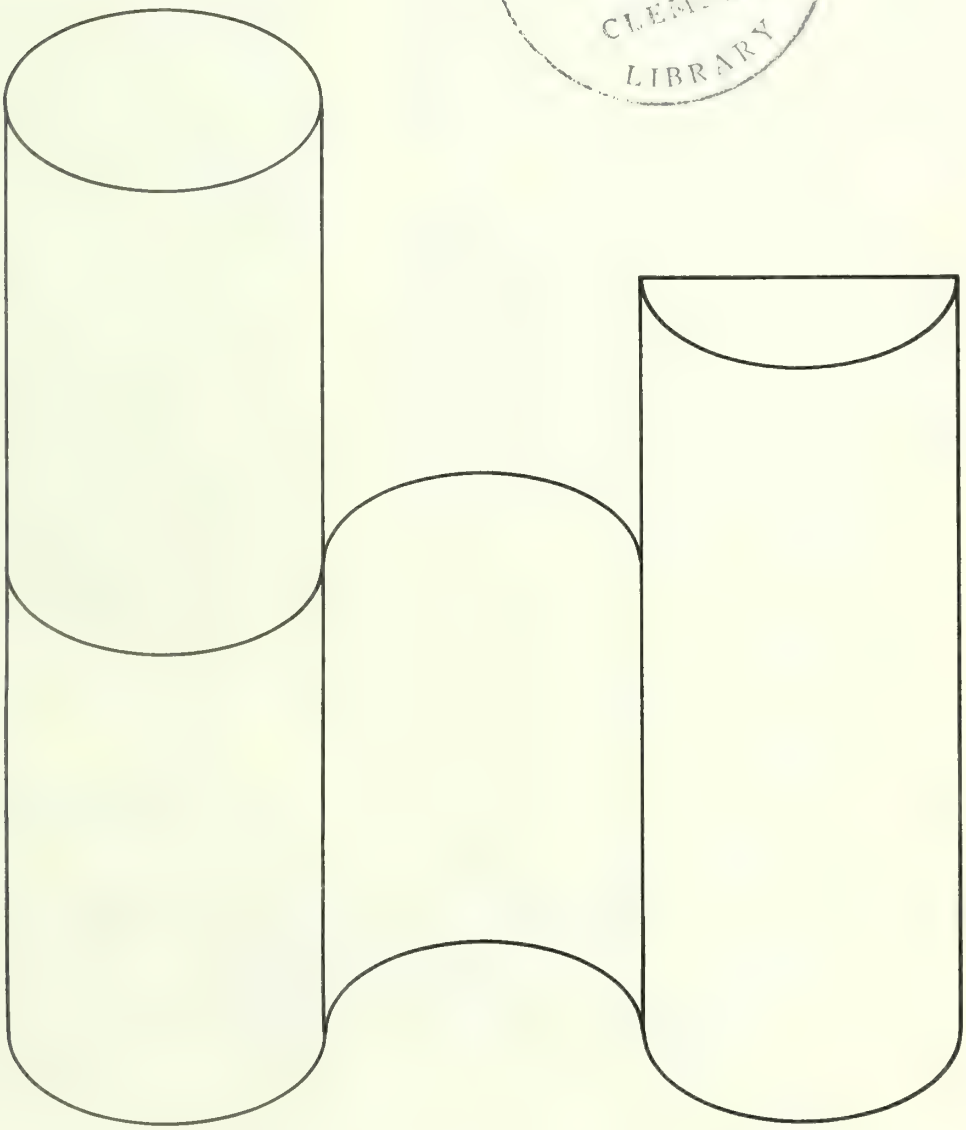

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A THERMAL COMPARISON AMONG SEVERAL BEVERAGE CAN SOLAR COLLECTORS

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One of the simplest and most efficient applications f solar energy is heating air for space heating or for lrying applications. In 1977 we built an air-heated olar collector from aluminum beverage cans (Chen *et l.* 1978) and tested for its effectiveness in drying umber in a solar kiln (Chen 1981), and in a solar-lehumidifier kiln (Chen *et al.* 1982). This solar col-ector was highly efficient and the solar kiln was able o dry 4/4 yellow-poplar from green to 15 percent noisture content (MC) in 8 days and the solar-lehumidifier kiln was able to dry 4/4 yellow poplar rom green to 8 percent MC in less than 6 days during he summers of 1978 and 1980.

We were encouraged by this performance and vanted to know more about this type of solar collector. Therefore, we designed and built four air-heated solar ollectors from aluminum beverage cans, each with a lifferent configuration of cans. We tested these col-ectors for four consecutive seasons from summer 981 to spring 1982 for their daily efficiencies. One of he collectors was also evaluated for one season for the ffect of air velocity across the collector on efficiency, emperature rise, and power consumption rate of the ollector.

DESIGN AND CONSTRUCTION

Our collectors differ from the common flat tray ollectors in one essential aspect; ours contain umerous sectioned beverage cans behind two layers f transparent fiberglass covers. These cans, sprayed vith two coats of flat black paint, act as both the black bsorber surface of the collector and the heat transfer urface to the passing air. The amount of air that omes into close contact with the absorber surface is reatly increased in this way as compared to a tandard flat tray collector while the total external collector area remains essentially unchanged. Two panes of fiberglass reinforced polyester ("Sunlite" from Kalwall Corp.[1]) were used as the collector cover and provided a stagnant air space that reduced heat loss from the collector back to the atmosphere. Air flowing through the collector was in contact with the heated can halves and also the inner layer of collector cover. The configurations for the four 2- by 8-foot test collectors are as follows (fig. 1).

All cans were tacked to ½-inch plywood.
Collector A—crosscut can halves tacked with ½-inch space between cans,
Collector B—crosscut can halves tacked side-by-side in contact,
Collector C—lengthwise cut can halves tacked parallel to air flow, and
Collector D—lengthwise cut can halves tacked perpendicular to air flow.

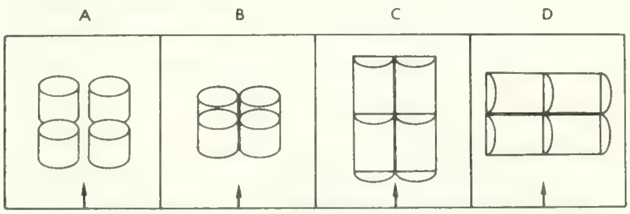

Figure 1.—*Different configurations of can halves used in the four test collectors. Arrows indicate the air-flow direction. A = crosscut can halves tacked with ½-inch space between cans, B = cross-cut can halves tacked side-by-side in contact, C = lengthwise cut can halves tacked parallel to air flow, and D = lengthwise cut can halves tacked perpendicular to air flow.*

[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

A reflector measuring 6 feet by 15½ feet was built by gluing a layer of 5 mills foil of Mylar cover on top of ½-inch exterior plywood to reflect more solar radiation (therefore more heat) to the collectors (fig. 2).

TEST FACILITY AND METHODS

The variables measured were insolation, air velocity flowing through collectors, blower power consumption, and temperature rise of the heated air with respect to the inlet air temperature.

Insolation was continuously measured by a precision spectral pyranometer and recorded by a strip-chart recorder. A hot wire anemometer was employed to measure different air velocities flowing through collectors with 20 points at each cross section (table 1). Inlet and outlet temperatures in the collectors were measured and recorded by means of thermocouples and a multi-channel recorder.

Daily efficiencies of the four collectors were tested on four mostly clear days per season (two days with the reflector and two days without) for four seasons at the second highest air velocity (V_2). The second highest air velocity was chosen because it was the highest air velocity the four blowers can produce without reaching their limit. When the reflector was tested, we visually adjusted it to reflect solar radiation to the full length (8 feet) of test collectors (fig. 2). The effect of air velocity on temperature rise, collector efficiency, and power consumption rate was tested on two mostly clear days in the spring of 1981 without the reflector on Collector B (crosscut can halves tacked side-by-side in contact). Six different air velocities were tested (table 1). Tests were conducted for 2 hours in the middle of the day to minimize the nonsteady state effects of insolation.

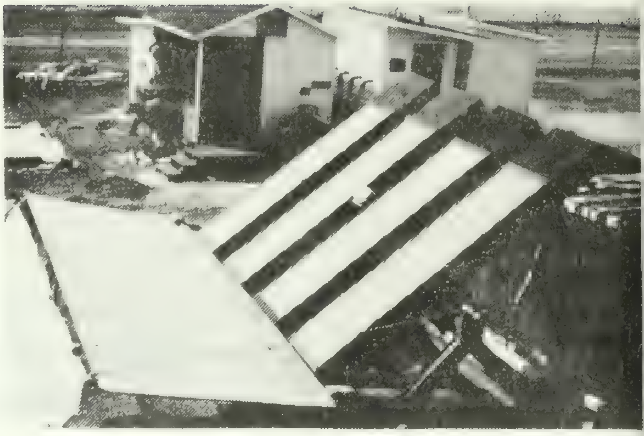

Figure 2.—*The four test collectors with the common reflector.*

COLLECTOR PERFORMANCE

A measure of collector performance is the instantaneous collector efficiency, η_c, defined by Duffie and Beckman (1980) as the ratio of the useful heat gain to the incident solar energy.

$$\eta_c = \frac{Q}{AI} \tag{1}$$

where

Q = the useful heat transferred to the working fluid in the solar collector (Btu/hr),

A = the collector area (ft^2), and

I = the insolation measured on the collector surface (Btu/ft^2/hr).

For our system with air as the working fluid,

$$Q = \dot{m}c_p\Delta T \tag{2}$$

where

$\dot{m}$ = the mass flow rate of air (lb/hr),

c_p = the specific heat of air at constant pressure (Btu/lb/°F),

Table 1.—*The effect of air velocity on instantaneous collector efficiency (η_c), temperature rise, and power consumption rate of collector*

Air velocity CF/SF/m[1]	Rank	Outlet temperature	Temperature rise	η_c	Power consumption rate
		°F	*°F*	*Percent*	*kW*
11.0	V_1	88.5	21.0	75	0.155
9.9	V_2	90.5	22.5	72	.081
8.7	V_3	93.0	24.5	68	.064
6.4	V_4	97.5	28.5	57	.054
4.7	V_5	102.0	31.5	48	.043
2.3	V_6	116.0	45.5	33	.020

[1]CF/SF/m = cubic foot of air/square foot of collector area/minute.

ΔT = the temperature rise (measured by thermocouples) of the air through the collectors. (°F)

Thus,

$$\eta_c = \frac{\dot{m}c_p\Delta T}{AI} \quad . \qquad (3)$$

For daily efficiency, η_d, the sum of the useful heat collected (ΣQ) was divided by the total unreflected solar radiation (ΣI) arriving at the solar collector. Thus,

$$\eta_d = \frac{\Sigma Q}{A\Sigma I} \quad . \qquad (4)$$

RESULTS AND DISCUSSION

The effect of can half configuration on daily efficiency of collectors was statistically significant. Duncan's multiple range test showed that Collectors D and B were not different from each other and that Collectors B and A were not different from each other. However, Collector D was superior to Collectors A and C, and Collector B was superior to Collector C (table 2). Even though Collector D (lengthwise cut can halves) requires only slightly more than one-half of the aluminum cans per square foot of collector area compared to Collector B (crosscut can halves), it is much more time-consuming and difficult to cut aluminum cans in half lengthwise than crosswise. Thus, the extra labor costs can easily overshadow the potential material savings of Collector D.

To show how the reflector affected insolation and heat collection, Collector D was monitored with and without the reflector during two consecutive days of almost identical daily insolation (2,008 Btu/ft² of September 20, 1981, vs. 1,986 Btu/ft² of September 21, 1981) (fig. 3). Both insolation and useful heat curves indicated that the fixed reflector was effective for 4 to 6 hours around noon. The fluctuation of the insolation of September 20, 1981 (with the reflector), was caused by the bumpy surface of the reflector. A heavier reflective material would probably provide a flatter reflector surface.

'able 2.—*Mean daily efficiencies (η_d) of the four test collectors*

uncan's grouping[1]		Mean η_d	Days	Collector[2]
		Percent	*Number*	
	a	73	16	D
b	a	71	16	B
b		69	16	A
	c	67	16	C

[1]Means with the same letter are not significantly different.
[2]Collector A—crosscut can halves tacked with ½-inch space etween cans,
Collector B—crosscut can halves tacked side-by-side in contact,
Collector C—lengthwise cut can halves tacked parallel to air flow, id
Collector D—lengthwise cut can halves tacked perpendicular to r flow.

The mean daily efficiency of the four collectors tested with the reflector was significantly higher than that of the same collectors tested without the reflector throughout the year (table 3). Collectors tested with the reflector averaged 73 percent daily efficiency compared to 67 percent daily efficiency without the reflector. Although the difference in mean daily efficiency between tests with and without the reflector was significant, the 6 percent increase in daily efficiency may not be enough to offset the extra costs for installing and maintaining the reflector.

The seasonal effect on the mean daily efficiency of the collectors was not statistically significant. Although the mean daily efficiencies among the four seasons appeared to increase with decreasing temperature of the season, the variation in daily efficiency between the 2 days tested within each season was as great as the difference shown among the four seasons.

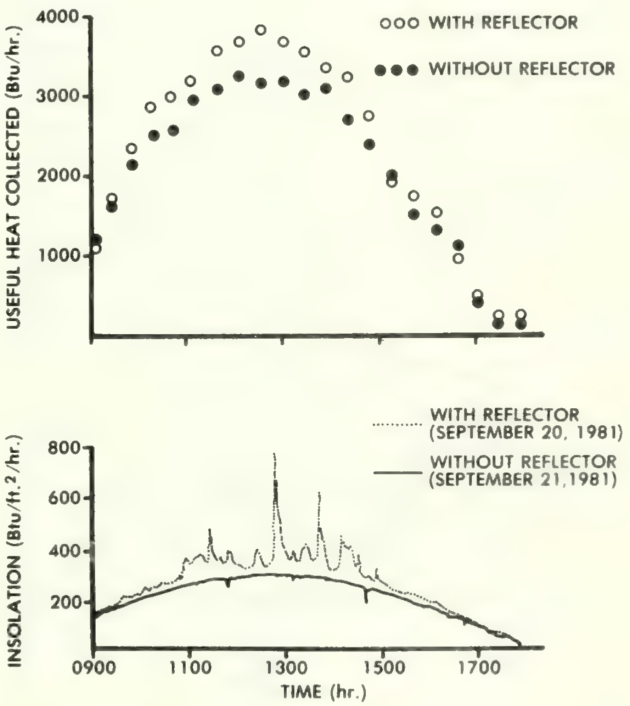

Figure 3.—*Effect of reflector on useful heat collection and insolation of Collector D during two consecutive days of almost identical daily insolation.*

Table 3.—*Mean daily efficiencies (η_d) of collectors with and without reflector*

Duncan's grouping[1]	Mean η_d	Days	Reflector
	Percent	*Number*	
a	73	32	Yes
b	67	32	No

[1]Means with the same letter are not significantly different from each other.

The interaction between the reflector and the season was significant (fig. 4). As expected, the mean daily efficiency curve without the reflector showed a trend of increasing efficiency with decreasing temperature of the season. However, the mean daily efficiency curve with the reflector did not show a corresponding increase in mean daily efficiency with decreasing temperature of the season. The fact was that all seasons, except summer, showed a mean daily efficiency of nearly 75 percent. It is possible that 75 percent daily efficiency is the maximum limit that this type of solar collector can reach.

Tests on the effects of six different air velocities showed that collector instantaneous efficiency varied proportionally to the air velocity across the collector and power consumption rate but inversely proportionally to the collector outlet temperature and temperature rise (outlet temperature - inlet temperature) (table 1). This information is useful to a solar kiln operator in maximizing collector efficiency and minimizing power consumption. For example, during the early stages of lumber drying, the kiln operator should use a high air velocity (V_2 or V_3) to collect solar energy at relatively higher efficiency but at relatively lower outlet temperature and at a moderate electrical energy cost. V_2 is approximately four times faster than the air velocity used in residential space heating. However, toward the end of drying, the kiln operator should raise kiln temperature by reducing air velocity in order to increase the outlet temperature of the collector and simultaneously reduce power consumption.

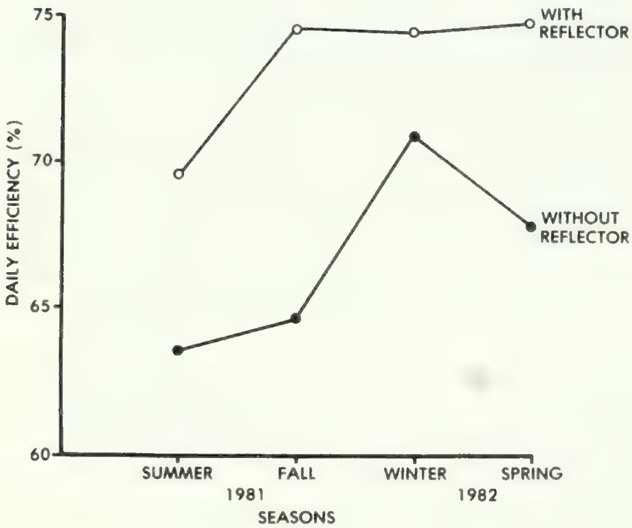

Figure 4.—*Demonstration of reflector-season interaction.*

CONCLUSIONS

1. Collector B (crosscut can halves tacked side-by-side in contact) was deemed to be the best among the four collectors tested when collector efficiency and collector cost were considered.
2. A reflector can increase collector efficiency, especially during noon hours.
3. Collector efficiency varies proportionally to the air velocity across the collector and power consumption rate but inversely proportionally to the collector outlet temperature and temperature rise.

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Four air-heated solar collectors were built using four different configurations of aluminum beverage cans. The collectors were then tested for four consecutive seasons for their daily efficiencies. One of the collectors was also evaluated for one season for the effect of air velocity on efficiency, temperature rise, and power consumption of the collector.

KEY WORDS: Efficiency, configuration, reflector, insolation, temperature rise, power consumption.

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Tables for Predicting the Slash Weight of Shortleaf Pine

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TABLES FOR PREDICTING THE SLASH WEIGHT OF SHORTLEAF PINE

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vn weight tables are used to provide estimates h loading that will result from timber cutting. nformation is useful for assessing potential tion of slash for fuelwood or other forest prod- predicting fire behavior potential, estimating emissions from prescribed fire, and guiding anagement decisions.

vn weight tables for shortleaf pine (*Pinus ta* Mill.) are available from several sources and Taras 1976, Crosby and Loomis 1967, sen and Loomis 1981, and Loomis *et al.* 1966). ugh these publications provide slash weight ites, they do not provide the standard fuel size s required in the Rothermel (1972) fire spread used in the National Fuel Appraisal Process h et al. 1981, Radloff *et al.* 1982).

tables presented here provide slash weights rown component fractions for shortleaf pine in issouri Ozarks. Weights are given for 3-inch inch merchantable tops. These tables supple- the publication "Handbook for Predicting Weight of Trees in the Northeast" (Freeman *et* 32).

BASIS FOR TABLES

mis *et al.* (1966) used diameter at breast height and crown ratio (the percent of total tree occupied by live crown) to formulate an equa- r estimating crown weight of shortleaf pine:

$$W = \frac{D^{1.736}R^{1.033}}{147.2} + \frac{D^{2.576}R^{1.458}}{1745.7} \qquad [1]$$

:
= dry weight of crowns (pounds),
= d.b.h (inches), and
= crown ratio (percent).

To construct tables 1 and 2, we added unmerchantable tip weights, corresponding to a 3-inch and a 4-inch merchantable top diameter, to the crown weight estimates from equation [1]. Weights of the 3- and 4-inch tips were estimated by using tip-weight data for ponderosa pine (Brown *et al.* 1977), assuming similar tip form and adjusting according to the relative wood densities for the two species. Shortleaf pine does have a sharper taper than ponderosa pine and would weigh somewhat less, but we considered this insignificant for the purposes of the tables.

Tables 3 and 4, which show the crown component fractions for standard fuel size classes, were constructed by using the branchwood and foliage weight tables given by Loomis *et al.* (1966). The tables give branchwood component weights for size classes of 0 to 0.5 inch, 0.6 to 1.5 inch, 1.6 to 3.0 inches, and greater than 3 inches. By adding tip weights to these tables and then using a Lagrange interpolation equation, crown component fractions were calculated for the standard branchwood fuel size classes of 0 to 1/4 inch, 1/4 to 1 inch, 1 to 3 inches, and more than 3 inches. These standard fuel size classes correspond to the 1-, 10-, 100-, and 1,000-hour timelag fuels described by Deeming *et al.* (1977).

Weights shown in table 1 for trees under 3 inches in diameter represent the total tree. Stem weights for these trees are based on an equation from Whittaker and Woodwell (1968). For users needing weight estimates for saplings, Edwards and McNab (1979) list equations for shortleaf pine and three other southern pines, using diameter at base of stem and total tree height as input variables.

USING THE TABLES

Crown Weight Tables

Recommended steps for using the crown weight tables are as follows:

Step 1.—Summarize the tree harvest data—numbers of trees to be cut per acre by d.b.h. class and crown ratio category. Always use a d.b.h. distribution rather than an average stand diameter. Using an average d.b.h. can result in a biased estimate because of nonlinear d.b.h.-weight relations.

Step 2.—Select the crown weight table appropriate for either a 3-inch (table 1) or 4-inch (table 2) top (weights based on a 2-inch top can be found in Clark and Taras (1976)), then (a) multiply the number of trees per acre to be harvested from each d.b.h. and crown ratio category by the table entry for that category; (b) sum the products over all categories to get the estimate of slash weight produced from the crowns of harvested trees; and (c) do the same with small diameter trees that have been trampled during logging, using the weights shown in table 1 for trees less than 3 inches in diameter.

Step 3.—Estimate slash weight in tons per acre for breakage and defect using the following equation (Brown *et al.* 1977):

$$W = \frac{(v) \times (f) \times (d)}{2000} \qquad [2]$$

where:

- W = the weight of debris from defect and breakage (tons per acre),
- v = merchantable volume to be cut (cubic feet per acre),
- f = fraction of merchantable volume to be left on the ground as defect and breakage, and
- d = density of wood (pounds per cubic foot).[1]

Step 4.—Summarize the total estimated weight of debris by adding:

a. Weight of crowns from cutting (step 2b).
b. Weight of trampling debris (step 2c).
c. Weight of defect (cull) and breakage material left in the woods after cutting (from step 3).
d. Weight of existing downed woody material from downed woody fuel inventory (Brown 1974).

This will give you the total predicted weigh[t] [of] debris remaining on the ground after cutting. T[he] debris includes both slash from cutting and [downed] material existing before cutting. These steps, as [well] as the use of tables 3 and 4 to estimate slash wei[ght] by fuel size classes, are illustrated in the follow[ing] example.

Example of Slash Prediction

Step 1.—This example involves a proposed t[hin]ning operation with utilization of all stem materi[al to] a 4-inch top. Assume all cut trees in the stand ha[ve] 50 percent crown ratio. Fifty stems per acre are t[o be] cut from each of three d.b.h. classes—5-inch, 6-i[nch,] and 7-inch. Further assume there will be no tr[am]pling damage and the preharvest fuel loading [is 3] tons per acre.

Step 2.—Using applicable weights (from tabl[e 2]) the calculations are as follows:

D.b.h.	Trees/acre	Lbs/tree	Lbs/acre	Tons/ac[re]
5	50	53	2,650	1.3
6	50	57	2,850	1.4
7	50	64	3,200	1.6
			8,700	4.3

Step 3.—In this example, assume the volum[e] that will be removed is 670 cubic feet per acre. [The] wood density (d) of shortleaf pine is 31.8 pounds [per] cubic foot. Breakage is judged to be 2 percent in [this] case and the defect left on the ground is estimate[d to] be 3 percent. The fraction (f) of merchantable vol[ume] expected to be left on the site is 0.02 + 0.03 or [0.05.] Substituting in equation [2] gives

$$W = \frac{670 \times 0.05 \times 31.8}{2000} = 0.53 \text{ tons per acre of de[bris]}$$

Step 4.—The fuel residue can now be estimate[d:]

a. Weight of crowns from cutting	=	4.3
b. Weight from trampling	=	.0
c. Weight from defect and breakage	=	.5
d. Existing downed woody material	=	3.0
Total		7.8

Thus, about 8 tons per acre of fuel residue will b[e on] the site after thinning.

Fuel Size Components

Fuel size class component fractions are give[n in] tables 3 and 4. The weight estimates for each fue[l]

[1] *The density of shortleaf pine is 31.8 pounds per cubic foot (U.S. Department of Agriculture 1974).*

s are calculated by multiplying the total crown ght for harvested trees in each d.b.h. class (step by the fraction shown in the appropriate table. the example described, the weight of crowns from 5-inch d.b.h. class estimated in step 2b—1.3 tons acre—is multiplied by 0.11—the foliage fraction 5-inch tree with a 50 percent crown ratio (table he result is 0.14 tons per acre. Similar values are rmined for each fuel size class and d.b.h.

n.	Tons/acre by d.b.h.	Fuel size class (inches) Foliage	0-1/4	1/4-1	1-3	3+
		tons per acre				
	1.3	0.14	0.05	0.14	0.35	0.61
	1.4	.21	.07	.22	.39	.50
	1.6	.27	.10	.32	.46	.45
		0.62	0.22	0.68	1.20	1.56

SUMMARY

ese tables can be used by forest managers to ob- total estimates of crown weight and weight of n components for shortleaf pine. The weights can sed for estimating material available for other t products, predicting fire behavior potential for us cutting options, estimating smoke emissions rescribed burns, and making fuel management ions.

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Table 1.—*Weight per shortleaf pine tree—total crown and unmerchantable tip to a 3-inch top. (Weights abo dashed line are total tree weights, including the stem)*

D.b.h. (inches)	Crown ratio (percent) 20	30	40	50	60	70
	Pounds					
1	2	2	2	2	2	2
2	7	8	8	9	9	9
3	19	20	21	22	23	25
4	17	19	21	23	26	29
5	17	21	24	28	33	38
6	18	23	29	36	42	50
7	21	28	37	46	56	67
8	24	35	47	60	74	89
9	29	43	59	78	96	116
10	35	53	75	98	123	150
11	42	66	93	124	155	190
12	51	81	115	154	196	239
13	60	98	142	189	242	295
14	72	119	172	232	295	361
15	85	142	207	279	357	439

Table 2.—*Weight per shortleaf pine tree—total crown and unmerchantable tip to a 4-inch top.*

D.b.h. (inches)	Crown ratio (percent) 20	30	40	50	60	70
	Pounds					
5	42	46	49	53	58	63
6	38	44	49	57	63	70
7	39	46	55	64	73	86
8	40	51	63	76	90	105
9	43	58	73	93	111	130
10	48	68	88	111	136	163
11	53	78	105	136	167	202
12	62	92	126	165	207	250
13	75	108	152	199	252	305
14	82	129	182	242	305	371
15	95	152	217	289	367	449

Table 3.—*Crown component fractions for shortleaf pine by fuel size classes, including tip to a 3-inch merchantable top. Note that 1- to 3-inch material above dashed line includes stem*

D.b.h. (inches)	Crown ratio (percent)						
	20	30	40	50	60	70	80
				FOLIAGE			
1-2	0.12	0.12	0.17	0.21	0.21	0.25	0.27
3	.05	.07	.09	.10	.12	.13	.14
4	.10	.13	.16	.18	.19	.20	.20
5	.15	.18	.20	.21	.22	.22	.23
6	.19	.22	.23	.23	.24	.24	.23
7	.22	.24	.24	.24	.23	.24	.23
8	.24	.24	.26	.24	.23	.22	.22
9	.25	.26	.24	.23	.22	.21	.21
10	.26	.24	.24	.23	.21	.20	.19
11	.26	.24	.23	.21	.20	.19	.18
12	.25	.23	.22	.20	.20	.18	.17
13	.25	.22	.21	.19	.18	.17	.16
14	.24	.22	.20	.19	.17	.16	
15	.23	.21	.19	.18	.17	.15	
				0- TO 1/4-INCH BRANCHWOOD			
1-2	0.01	0.01	0.01	0.04	0.04	0.04	0.06
3	.02	.03	.03	.04	.04	.05	.05
4	.04	.05	.06	.06	.07	.07	.07
5	.05	.07	.07	.07	.07	.07	.08
6	.07	.08	.08	.08	.08	.08	.08
7	.08	.08	.08	.08	.09	.09	.09
8	.08	.08	.09	.09	.09	.09	.08
9	.08	.09	.09	.09	.09	.09	.08
10	.09	.09	.09	.08	.09	.08	.08
11	.09	.09	.09	.08	.08	.08	.08
12	.09	.09	.09	.08	.08	.08	.07
13	.09	.09	.08	.08	.07	.07	.06
14	.09	.08	.08	.08	.07	.07	
15	.09	.08	.07	.07	.07	.06	
				1/4- TO 1-INCH BRANCHWOOD			
1-2	0.44	0.44	0.42	0.40	0.40	0.38	0.38
3	.05	.06	.07	.08	.10	.11	.12
4	.08	.10	.13	.15	.17	.19	.21
5	.12	.15	.18	.21	.24	.25	.25

(Table 3 continued on next page)

(Table 3 continued)

D.b.h. (inches)	Crown ratio (percent)						
	20	30	40	50	60	70	80
6	.16	.21	.24	.26	.26	.26	.26
7	.20	.25	.27	.27	.27	.26	.25
8	.24	.28	.27	.27	.26	.25	.23
9	.27	.28	.28	.26	.24	.22	.20
10	.28	.28	.26	.23	.21	.20	.19
11	.29	.27	.24	.22	.19	.18	.18
12	.28	.25	.22	.19	.18	.18	.16
13	.28	.24	.20	.18	.17	.16	.15
14	.26	.22	.19	.18	.16	.15	
15	.25	.20	.18	.16	.15	.14	
				1- TO 3-INCH BRANCHWOOD			
1-2	0.43	0.43	0.40	0.35	0.35	0.33	0.29
3	.53	.51	.49	.48	.46	.45	.43
4	.78	.72	.65	.61	.57	.54	.52
5	.68	.60	.55	.51	.47	.46	.44
6	.58	.49	.45	.43	.42	.42	.43
7	.50	.43	.41	.41	.41	.41	.43
8	.44	.40	.38	.40	.42	.44	.47
9	.40	.37	.39	.42	.45	.48	.51
10	.37	.39	.41	.46	.49	.52	.54
11	.36	.40	.44	.49	.53	.54	.53
12	.38	.43	.47	.53	.54	.53	.53
13	.38	.45	.51	.54	.54	.53	.49
14	.41	.48	.53	.52	.53	.48	
15	.43	.51	.54	.53	.48	.39	
				>3-INCH BRANCHWOOD			
3	0.35	0.33	0.32	0.30	0.28	0.26	0.26
4							
5							
6							
7							
8							
9							
10							
11						.01	.03
12						.03	.07
13				.01	.04	.07	.14
14				.03	.07	.14	
15			.02	.06	.13	.26	

Table 4.—*Crown component fractions for shortleaf pine by fuel size classes, including tip to a 4-inch merchantable top*

D.b.h. (inches)	Crown ratio (percent)						
	20	30	40	50	60	70	80
				FOLIAGE			
5	0.06	0.08	0.10	0.11	0.13	0.13	0.14
6	.09	.12	.14	.15	.16	.17	.18
7	.12	.14	.16	.17	.18	.19	.19
8	.15	.17	.19	.19	.19	.19	.19
9	.17	.19	.19	.19	.19	.19	.19
10	.19	.20	.20	.20	.19	.19	.18
11	.21	.20	.20	.19	.19	.18	.18
12	.21	.21	.20	.19	.19	.17	.17
13	.20	.20	.19	.19	.17	.17	.16
14	.21	.20	.19	.18	.17	.16	
15	.21	.20	.18	.17	.16	.15	
				0- TO 1/4-INCH BRANCHWOOD			
5	0.02	0.03	0.03	0.04	0.04	0.04	0.05
6	.03	.04	.04	.05	.05	.06	.06
7	.04	.05	.06	.06	.07	.07	.08
8	.05	.06	.06	.07	.07	.07	.07
9	.05	.07	.07	.08	.08	.08	.07
10	.06	.07	.07	.07	.08	.07	.07
11	.06	.08	.08	.08	.07	.07	.07
12	.07	.08	.08	.07	.07	.07	.07
13	.07	.08	.08	.08	.07	.07	.06
14	.08	.08	.07	.07	.07	.06	
15	.08	.08	.07	.07	.07	.06	
				1/4- TO 1-INCH BRANCHWOOD			
5	0.05	0.07	0.09	0.11	0.13	0.15	0.16
6	.08	.11	.14	.16	.18	.18	.20
7	.11	.15	.18	.20	.20	.20	.21
8	.14	.19	.20	.22	.22	.21	.20
9	.18	.21	.22	.22	.21	.19	.18
10	.20	.22	.22	.21	.19	.18	.17
11	.22	.23	.21	.20	.18	.17	.17
12	.23	.22	.20	.18	.17	.17	.16
13	.22	.22	.19	.17	.17	.16	.14
14	.23	.20	.18	.17	.16	.15	
15	.23	.19	.17	.16	.14	.13	

(Table 4 continued on next page)

(Table 4 continued)

D.b.h. (inches)	Crown ratio (percent) 20	30	40	50	60	70	80
				1- TO 3-INCH BRANCHWOOD			
5	0.28	0.27	0.27	0.27	0.27	0.28	0.27
6	.27	.27	.27	.28	.28	.31	.29
7	.27	.27	.27	.29	.31	.33	.34
8	.27	.27	.29	.31	.34	.38	.41
9	.26	.28	.32	.35	.39	.43	.46
10	.27	.31	.35	.40	.44	.48	.51
11	.29	.34	.40	.44	.49	.51	.51
12	.31	.38	.43	.49	.51	.51	.51
13	.37	.40	.47	.51	.51	.51	.49
14	.35	.44	.50	.51	.50	.47	
15	.38	.47	.52	.51	.47	.39	
				> 3-INCH BRANCHWOOD			
5	0.59	0.55	0.51	0.47	0.43	0.40	0.38
6	.53	.46	.41	.36	.33	.28	.27
7	.46	.39	.33	.28	.24	.21	.18
8	.39	.31	.26	.21	.18	.15	.13
9	.34	.25	.20	.16	.13	.11	.10
10	.28	.20	.16	.12	.10	.08	.07
11	.22	.15	.11	.09	.07	.07	.07
12	.18	.11	.09	.07	.06	.08	.09
13	.14	.10	.07	.05	.08	.09	.15
14	.13	.08	.06	.07	.10	.16	
15	.10	.06	.06	.09	.16	.27	

Freeman, Duane R.; Roussopoulos, Peter J.
Tables for predicting the slash weight of shortleaf pine. Gen. Tech. Rep. NC-93. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 8 p.

The tables provided here estimate crown weights of shortleaf pine (*Pinus echinata* Mill.) from measurements of diameter (d.b.h.) and crown ratio, for both a 3-inch and a 4-inch merchantable top. Crown component fractions for standard fuel size classes are also presented.

Key Words: Fuel management, debris prediction, *Pinus echinata*

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Modeling the Effect of Competition on Tree Diameter Growth as Applied in Stems

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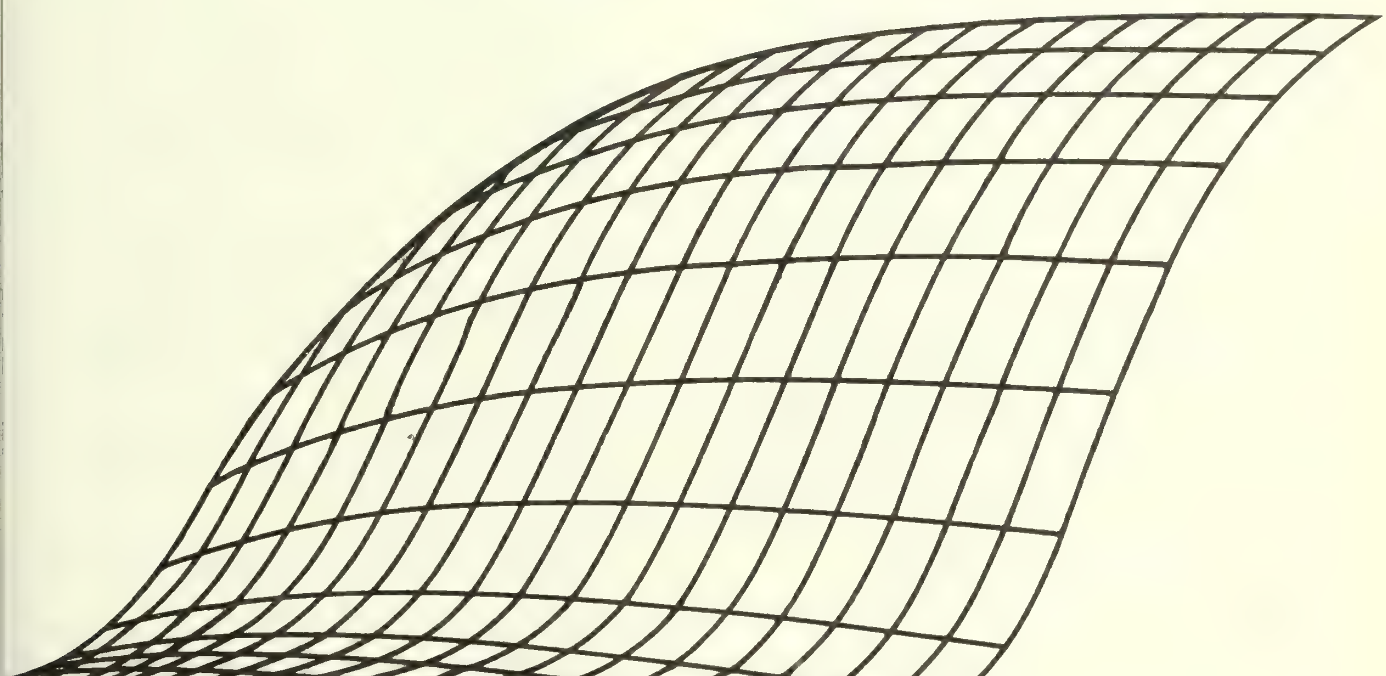

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MODELING THE EFFECT OF COMPETITION ON TREE DIAMETER GROWTH AS APPLIED IN STEMS

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Competition is a vital ingredient in individual-tree rowth models. The advent of large computer-based ee-growth simulation systems has greatly increased e detail of competition that can be included. Many the competition indices now available require the cation of competing trees, costly data to acquire. owever, many potential tree growth model users ly have tree-diameters data. For them, the more eneralized distance-independent tree growth model lfills a real need. In this paper I present a sysmatic approach to modeling competition that does ot require information about location of trees in a and.

The competition model described is currently used STEMS, a Stand and Tree Evaluation and lodeling System (Belcher *et al.* 1982). STEMS is a vision of an earlier North Central Station tree rowth projection system that was a part of a Forest esources Evaluation Program (FREP). A collection papers detailing the development of the initial rowth projection system has been published (USDA orest Service 1979).

A basic premise in the design logic of these forest rowth projection systems is that the growth of a tree the product of its potential growth and a modifier of at potential due to competition (Leary and Holdway 1979):

$$\text{Annual change tree diameter} = \left[\begin{array}{c}\text{potential yearly}\\ \text{d.b.h. growth}\end{array}\right] \cdot \left[\begin{array}{c}\text{fraction of the potential}\\ \text{growth actually achieved}\end{array}\right] \quad (1)$$

Potential growth, the growth possible when trees re free of competition, was estimated using the rowth attained by the most rapidly growing domiant and codominant trees (Hahn and Leary 1979). iameter growth, diameter, and crown ratio from ese trees along with their stand site index were used develop the model for potential growth. A model for timating potential tree diameter growth was develbed for each major Lake States tree species.

The modifer function, which accounts for those competitive processes that reduce the potential growth to actual growth (Leary and Holdaway 1979), depends on the characteristics of the stand. This paper shows how this modifer was developed and how competition is handled in it.

THE FOREST COMMUNITY

The modifier function mathematically represents the effect of the forest community on a single tree's growth. The following stand characteristics are important in describing this environment for any tree or group of trees:

1. *Stand density* is a measure of crowding, expressed in terms of stand basal area. The greater the density, the slower each tree grows. The modifier, a nonlinear function of basal area, approaches 1 for low levels of basal area and approaches 0 for high levels of basal area.
2. *Stand structure* is the distribution of tree diameters in a stand. Two measures of stand structure are absolute tree size and relative tree size as measured by diameter.
3. *Stand species composition* is the stand's makeup by species. In addition to the tree size effect within species, mixed species stands have the effects of interaction among species.

A modifier function should account for all three of these stand social characteristics.

PREVIOUS MODEL

Form

The original model was a stand component model. Each tree list was broken down into a maximum of four species groups and each species group was divided into two size classes. These divisions were

called components. Each stand component was projected as a whole, and later the component's growth was allocated to the individual trees. Species-specific coefficients were calibrated for trees growing under nearly pure conditions. However, the component approach also allowed for interactions between components of different species. The original modifier of the potential due to competition was (Leary and Holdaway 1979):

$$1 - e^{-\beta(AD)\,BA} \quad (2)$$

where BA was the stand basal area in square feet per acre and β (AD) was a function of the average diameter (AD) of the stand (fig. 1). This simple nonlinear function had the desirable property that the modifier approached 1 for low levels of basal areas and approached 0 at high basal areas.

The original form contained a complex expression for basal area. β remained constant for any stand component of average diameter AD while the basal area of the component was altered via the concept of "effective basal area". A separate rule was used to allocate growth to the trees in each component according to its relative position in the component.

Shortcomings

The stand component approach has several limitations. First, no data were available for determining the modifier coefficients for the less abundant species because the necessary pure[1] stands for these species were not available.

Second, even for the abundant species it was almost impossible to find pure stands with very small or very large average diameters. This meant that projections made with the stand component model were only good for most major species over normal d.b.h. ranges. Outside of these ranges the model did not project growth well, especially for minor species and young stands. This could cause problems in growing regeneration stands, because these young stands would be far out of the range of the calibration data.

Finally, when the modifier (2) was tested on long range projections of red pine plantations, stand basal areas were obtained that exceeded known biological limits. The modifier remained high within very dense stands (fig. 1), especially for medium-sized overstory trees. These trees were projected to grow at 20 to 30 percent of their potential though basal areas were as high as 400 to 500 square feet.

[1]*A stand is considered "pure" if more than 75 percent of the stand is one species.*

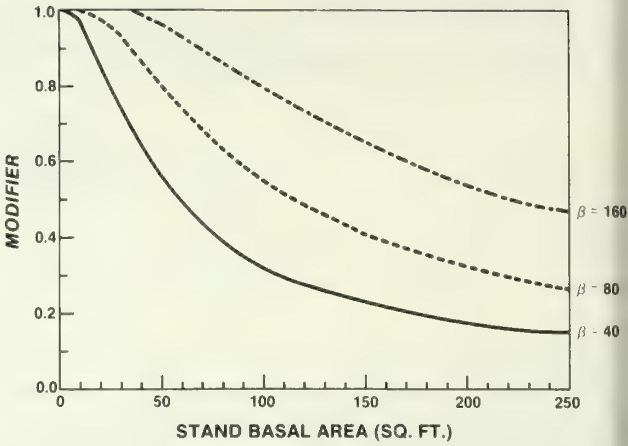


Figure 1.—*The behavior of the original modifier form in equation (2) and the initially proposed form in equation (3) for three different* β(or Bo) values.

PRESENT MODEL

Development

Initially, an individual-tree model similar to the original stand component model was proposed:

$$\text{MODIFIER} = 1 - e^{-Bo(AD,R)/BA}. \quad (3)$$

Here Bo is a species-specific function of the stand average diameter (AD) and the ratio (R) of the tree's diameter to the stand's AD. In this model a tree's growth under competition depends on the stand's average tree size and the tree's relative position in the stand. Interactions among species are not included.

The basal area in equation (3) is constant for all trees in a stand. However, the Bo term is different for each individual tree (fig. 1). With this model, the higher the Bo value within a given stand the higher the proportion of potential achieved.

To better account for absolute and relative size effects, we replaced Bo in equation (3) by two separate multiplicative functions. Written in notational form:

$$Bo = f(R) \cdot g(AD)\,. \quad (4)$$

This adjusts the stand's average diameter effect by each tree's relative position in the stand. No adjustment is made for a tree of mean stand diameter (i.e. f(R=1) = 1). If the tree is an "overstory" tree (one with a large relative diameter), the average diameter effect is increased accordingly; it is decreased for an "understory" tree (one with a small relative diameter).

From graphs of the data expressing Bo as a function of average diameter and relative diameter asses, appropriate functions were sought for g(AD) nd f(R). A fairly simple two parameter function, $(AD+1)^{c_2}$, used for g(AD) (fig. 2) fits the data well hile allowing for monotonic decreasing curves that re evident on a few species. It does not fluctuate harply up or down but maintains realistic behavior eyond the general range of the existing data.

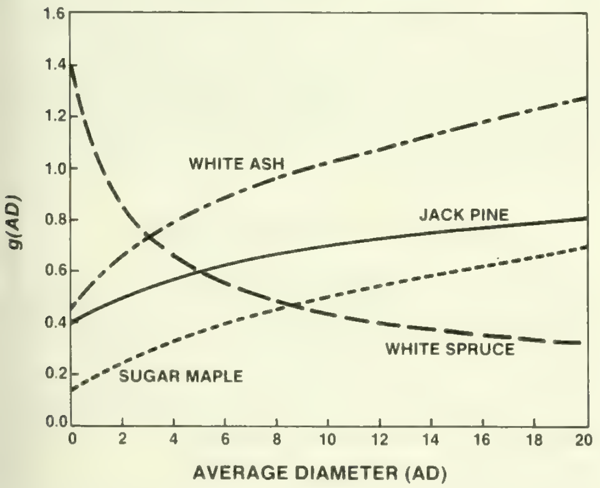
For many species the relative function appears to e nearly linear over the central range of the data. owever, the function appears to level off for data utside this central range, implying that both very mall understory trees and very large overstory trees symptotically approach limiting values. Thus a gmoid function plus a constant, b_4 , were used to stimate the relative effect (fig. 3). As a tree's relative osition in the stand approaches zero, f(R) will approach b_4 . This provides a very small tree on an open-rown stand of large trees some minimal amount of rowth that will permit it to struggle along.

Because of its shape, this modifier function still ould seriously overgrow stands on long-term projecons (fig. 1). Therefore we added a maximum stand asal area term that would limit tree size. Hence the odifier became:

$$\text{IODIFIER} = 1 - e^{-Bo[(BAmax-BA)/BA]^{p}}. \qquad (5)$$

Vhen BA is greater than or equal to BAmax, the odifier equals zero. Because we had little data on pecies maximum basal areas, these values were set mpirically.

The power p on the basal area term adds flexibility the resulting curves. The value of 0.5 was chosen



igure 2.—*Average diameter effect g(AD) for selected Lake States tree species.*

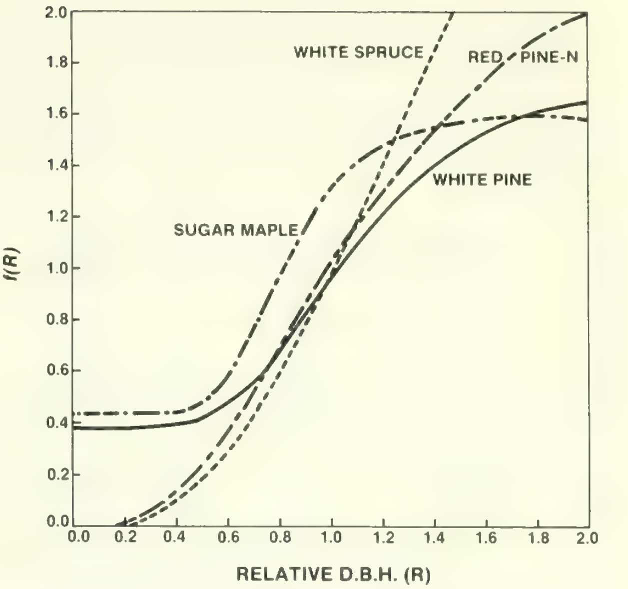


Figure 3.—*Relative diameter effect f(R) for selected Lake States tree species.*

based on the comparison of graphs of equation (5) for p values of 0.5, 1.0, and 2.0 with graphs of the actual data. The final form of the modifier becomes:

$$\text{MODIFIER} = 1 - e^{-Bo[(BAmax-BA)/BA]^{0.5}}. \qquad (6)$$

where Bo = f(R) ·g(AD).

Recall that the effect of the surrounding forest community on a tree or group of trees is described by stand density, structure (i.e., actual and relative tree size), and species composition (including species interaction). Equation (6) accounts for all of these except species interaction. From preliminary model testing it appeared that for most species the relative diameter effect was the most important, followed by the average diameter effect. The species interaction effect was usually small so was not included in the model.

Final Form

The final form of the model is:

$$\text{MODIFIER} = 1 - e^{-f(R)\cdot g(AD)\cdot[(BAmax-BA)/BA]^{.5}} \qquad (7)$$

$$\text{where } f(R) = b_1\left[1 - e^{b_2 R}\right]^{b_3} + b_4, \qquad (8)$$

$$g(AD) = c_1\,(AD + 1)^{c_2}, \qquad (9)$$

and b_1 , b_2 , b_3 , b_4 , c_1 , and c_2 are unknown numerical constants.

To avoid computing implausible values for the parameters, the following restrictions were made: $b_1 \leqslant 5$, $b_4 \geqslant 0$, $c_1 > 0$, and $c_2 \leqslant 1$. In equation (8), $b_1 + b_4$ is the asymptotic maximum of the relative diameter effect, b_4 is its minimum value, b_2 is a rate parameter,

and b_3 is a rate and shape parameter. In expression (9), c_1 is the y-intercept of the average diameter effect and c_2 provides a measure of its slope. When c_2 equals 1.0, the function is linear. When c_2 is negative, the average diameter effect is decreasing with increasing diameter.

ESTIMATING COEFFICIENTS

Data Base

Now that the form for the modifer was set, we had to determine species-specific constants for it. To do this we first had to calculate potential growth from the measured d.b.h., crown ratio, and plot site index. Then using this known potential growth, as well as the measured realized growth, we could estimate the unknown coefficients in the modifier function.

Certain restrictions were imposed on the data before tree observations could be used to derive the constants. To be included in the study a tree needed to have survived over the time interval chosen, to have a measured crown ratio and plot site index to obtain the growth potential, and to have a measured diameter at the beginning and end of the interval so growth could be determined for the period. Two growth intervals were selected on each plot to obtain a maximum of two observations per tree: one from the final measurement back approximately 10 years, and the other from the first measurement forward approximately 10 years. In this way fuller use was made of the data base because frequently trees classified as ingrowth, dead, or cut had survived through one of the two intervals. If the two measurements overlapped, only the last interval was used.

We only included plots that had no major disturbance (i.e., losses to excessive mortality or to cutting) during the growth interval. For example, if the final basal area was less than 90 percent of the initial basal area, we assumed that a major disturbance occurred and did not use the plot.

Permanent growth plot data were available from 44 different studies in Minnesota, Wisconsin, and Michigan (Christensen *et al.* 1979). There were 1,501 plots containing 92,649 trees remeasured at least once. From this, a total of 72,923 tree observations were obtained. Because previous analyses showed that red pine in natural stands and plantations grow differently (Leary *et al.* 1979), we separated the data for natural-grown and plantation-grown red pine. We did not separate the data for any other species.

Methods

For each tree we calculated the growth potential using the equation and coefficients as described in Hahn and Leary (1979). We calculated the modifier, the proportion of potential growth achieved, using

$$\underset{\text{(i.e., modifier)}}{\text{proportion of potential growth}} = \frac{\text{actual growth}}{\text{calculated potential growth}}\,. \qquad (10)$$

Trees were grouped on the basis of stand basal area (BA), stand average diameter (AD), and their relative position in the stand (R)—all variables in the modifier function. Cells were formed for each species using 2 inch average diameter classes, 25 square feet basal area classes, and 10 percent relative diameter classes. The mean MODIFER was computed for each cell.

For each species these cell modifier observations were graphed for basal area levels coded by relative diameter class. Species with a large data base showed distinct trends consistent with the general form of the function in equation (6). The logical maximum basal area approached by each species regardless of site was determined from these graphs. These maximums were checked against expectations obtained from the scientific judgment of foresters before being used.

All six parameters in equations (8) and (9) can be estimated simultaneously, but the natural condition where R = 1 doesn't necessarily yield f(1)=1. This makes it difficult to compare the relative effect among species. This problem can be avoided by fitting the model in two steps as follows: first, estimate the coefficients in the g(AD) function setting f(R) to 1; then substitute the c_1 and c_2 coefficients of equation (9) into equation (7) and estimate the four parameters in f(R), equation (8). With this procedure f(R) will approximate 1 for R=1.

RESULTS OF ANALYSIS

Using the modifier model, we computed coefficients for 26 Lake States species (table 1, figs. 2 and 3).

Table 1.—*Species coefficients for modifier function[1] for major Lake States tree species*

Species	Observations	BAmax	c_1	c_2	b_1	b_2	b_3	b_4
	Number	*Ft²/ac*						
Jack pine	8,934	225	0.402	0.230	1.78	-3.00	16.20	0.227
Red pine-N[2]	6,067	300	2.030	-.354	.72	-10.90	1,688.30	.375
Red pine-P[2]	20,224	350	.441	.173	2.31	-1.67	3.94	.000
White pine	1,162	300	.097	.755	1.36	-2.64	11.50	.386
White spruce	2,440	350	1.507	-.520	5.00	-1.01	3.64	.000
Balsam fir	4,376	325	.927	-.299	1.76	-1.51	2.63	.233
Black spruce	2,870	300	.522	.173	3.80	-1.52	6.54	.348
Tamarack	57	250	.039	1.000			Use jack pine[3]	
N. white-cedar	2,782	350	.526	.136	2.54	-1.14	2.26	.000
Hemlock	334	300	.046	1.000	1.27	-1.34	1.05	.000
Black ash	174	250	.260	.419	5.00	-.57	1.83	.063
Cottonwood				Use red maple[4]				
Silver maple				Use red maple[4]				
Red maple	1,514	250	.181	.445	1.40	-2.03	10.40	.694
Elm	1,585	250	.100	.629	5.00	-.97	4.40	.268
Yellow birch	656	250	.202	.454	.68	-10.97	1,568.20	.483
Basswood	2,096	250	.353	.182	1.59	-3.27	26.70	.412
Sugar maple	9,383	250	.142	.524	1.17	-4.59	29.19	.430
White ash	1,500	250	.453	.340	5.00	-1.38	8.26	.326
White oak	623	250	.051	1.000			Use select red oak[3]	
Select red oak	1,307	275	.278	.365	1.98	-.97	1.64	.000
Other red oak	80	250	1.365	-.208			Use select red oak[3]	
Hickory	507	250	.280	.228	1.66	-2.62	9.97	.515
Bigtooth aspen	94	250	.093	1.000	1.13	-4.64	164.62	.648
Quaking aspen	2,944	250	.209	.543	1.08	-6.60	346.09	.395
Paper birch	1,214	275	.110	.678	1.98	-1.75	3.67	.232

[1]$\text{MODIFIER} = 1 - e^{-f(R) \cdot g(AD) \cdot [(BAmax - BA)/BA]^{.5}}$

where $f(R) = b_1 \left[1 - e^{b_2 R} \right]^{b_3} + b_4$, and

$g(AD) = c_1 \, (AD + 1)^{c_2}$.

[2]*P = plantation*

N = natural stand.

[3]*Use coefficients for similar species because data for these species were insufficient to reliably estimate the relative diameter effect.*

[4]*Use red maple coefficients because no data were available for these species.*

Illustration

To demonstrate graphically how the modifier func- on behaves, consider a select red oak stand with ean stand diameter of 10 inches. The model is used evaluate the growth of five trees having diameters 4, 7, 10, 13, and 16 inches. The corresponding elative diameter values (R) of these trees are 0.4, 0.7, 0, 1.3, and 1.6. Using a series of species-specific curves for these five R values (fig. 4), Bo (f(R)•g(AD) can be estimated given any AD and R values. Incorporating these five Bo values into the modifier function in equation (6) yields figure 5.

In a stand with low basal area, BA_1, the large trees will grow at nearly full potential but the understory trees will not—their growth will be somewhat restricted. In a stand with high basal area, BA_2, the overstory trees will grow a little, even under these

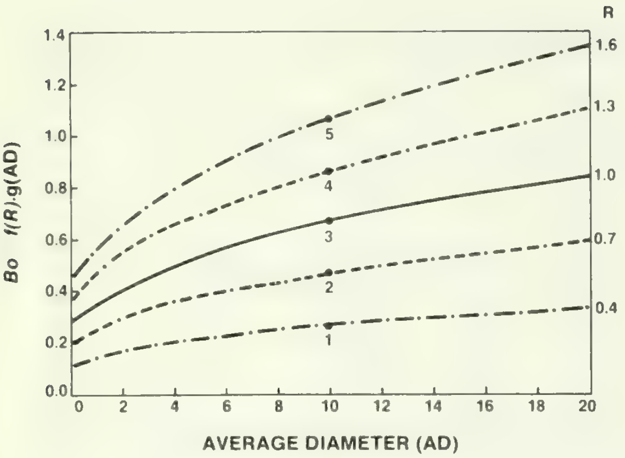


Figure 4.—*Various relative diameter curves added onto the basic average diameter effect curve for select red oak. For any given AD and R values Bo can be found. The five points indicate Bo values for the trees in the example.*

adverse conditions, but growth of the understory trees will be severely restricted.

The same type of results can be shown in a different form using three-dimensional graphs. Graphs of the modifier function for sugar maple at basal areas of 75 and 150 sq. ft./acre indicate how the effects of average diameter and relative diameter combine to influence the proportion of the potential growth realized (fig. 6).

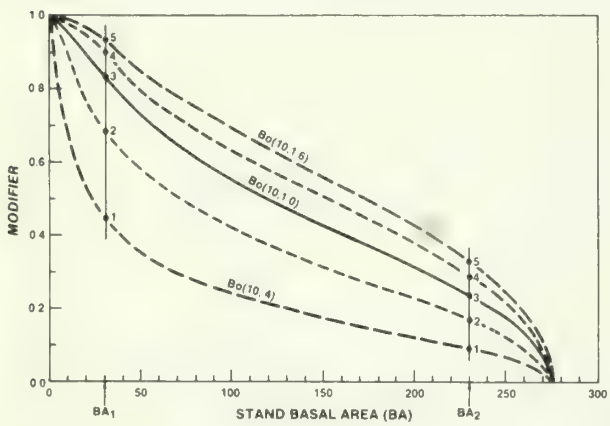


Figure 5.—*Modifier function for five Bo values corresponding to relative diameters of 0.4, 0.7, 1.0, 1.3, and 1.6 within a select red oak stand having a 10 inch average stand diameter at high and at low basal area.*

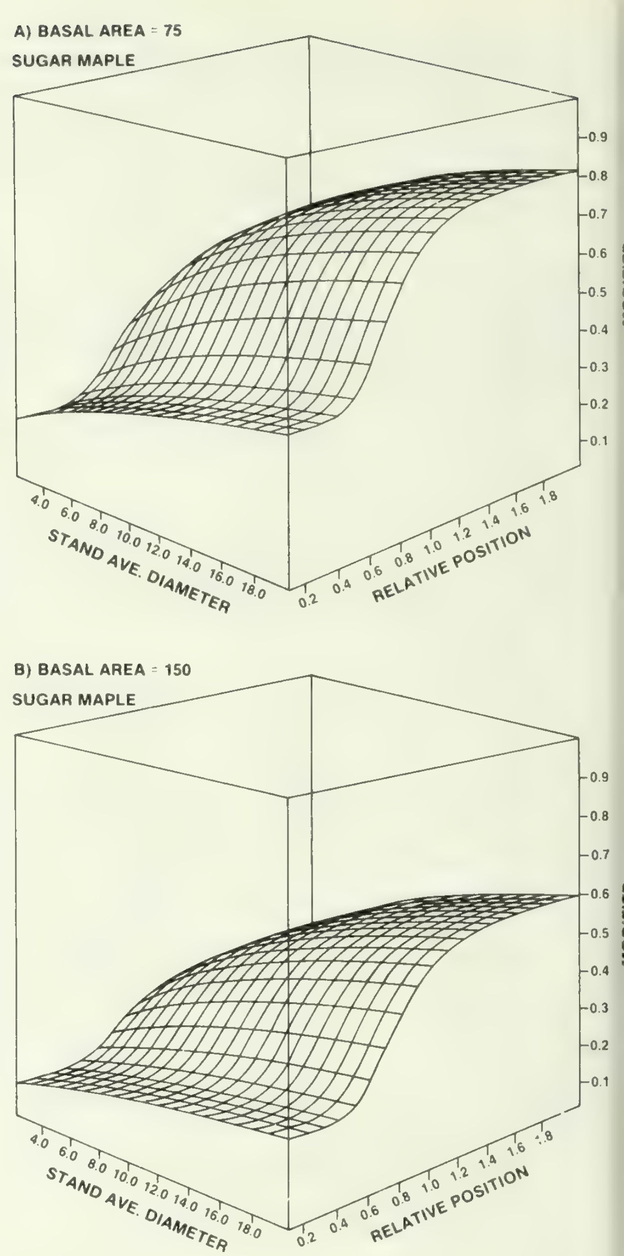


Figure 6.—*The modifier function for sugar maple for stand basal areas of 75 and 150 sq. ft./acre.*

Biological Considerations

What happens as an untreated stand approaches the maximum basal area? Overstory trees will still be given some growth whereas understory trees will approach zero growth. In STEMS, as the growth rate decreases the probability of death increases. This reduces the basal area and releases the larger trees slightly. Therefore, the stand will approach an equilibrium just below the maximum basal area. We suspect that for some species maximum basal area is

elated to site, with better sites having higher maxi-
ıum basal area. But we did not have the data to test
ıis.

Gingrich (1967) has shown that stands with large verage diameter can support more basal area withut adversely affecting the growth of the individual ree. The average diameter effect for most species onfirms this (fig. 2). For example, a 10 inch tree in a tand with mean d.b.h. 10 inches will have greater rowth than a 4 inch tree in a 4 inch stand, assuming qual stand basal area. This seems to be a reasonable esult. That, however, does not account for those pecies with decreasing average diameter effects (e.g., hite spruce in fig. 2). These species may have faulty rowth potential functions (calibrated from a limited ange of data) and the modifier function may be orced to compensate for these errors.

What happens if a previously set maximum basal rea (table 1) doesn't seem appropriate for a particuır forest condition? In theory, the data should be refit nd coefficients determined for the new BAMAX.

In practice, if you are willing to accept minimal de effects, BAMAX can be adjusted without retting the data and changing the coefficients. To lustrate, a minimal change in BAMAX of 25 square eet only slightly alters the value of the modifier unction in equation (7). For the extreme change of ncreasing BAMAX from 275 to 350 square feet (fig.), the modifier for all trees would be increased by .02 to 0.10 on plots of average density, say 100 to 150 quare feet. The change in the proportion of growth ould be greater than 0.10 for plot BA's close to the ew BAMAX. Likewise, a similar decrease in AMAX produces corresponding decreases in the nodifier. Adjusting BAMAX, which produces slight ncreases or decreases in the growth projections, nables users to account more accurately for known ocal conditions or to include the influence of good or oor sites.

EVALUATION

To evaluate model performance, we used the TEMS system containing the modifier function (7) n two sets of data. The first was a systematic sample f every fifth plot from the calibration data base. Any narked bias at this point would indicate a basic flaw n the mathematical model used to describe the ystem.

The projection system can perform well over the road region from which the calibration data were rawn and still fail when representing growth of maller subregions. Therefore, we also tested the model against several independent data sets (Schaeffer 1980 and Taylor 1979). This second data set (or validation data base) consisted of five independent data sources from the Lake States region (Holdaway and Brand 1983).

We also tested the new model against the best available previous model, equation (2). The same growth potential function was used in both models. Crown ratio is a variable in the potential function. To avoid introducing a crown ratio error, we only used trees with measured crown ratios.

The growth for each tree on the test plots that had survived at the last measurement was projected for the preceding time interval. Tree and stand characteristics at the first measurement were used as initial conditions for the projection. Cut trees were removed and ingrowth trees added to the projection tree list in the appropriate year. Final predicted and observed d.b.h.'s, along with the pertinent stand and tree data, were recorded. Then we calculated each tree's d.b.h. error (i.e., predicted minus observed d.b.h.).

The projection intervals ranged from 9 years to 17 years. The errors were standardized to 10 years using the adjustment:

$$\frac{\text{(predicted d.b.h. - observed d.b.h)}}{\text{number of years in measurement interval}} \times 10 \qquad (11)$$

A positive error means growth was overpredicted.

We analyzed the results for accuracy and precision by calculating the mean and standard deviation of the 10 year errors (table 2). If the predictions were perfect, all errors would be zero and both the mean and standard deviation would be zero. The further these values are from zero, the greater the bias and variability.

We also investigated species interaction. For the validation data, the mean d.b.h. error for each species was broken down by the forest type in which it occurred. These results help answer questions such as:

Table 2.—*Summary of the mean and standard deviation of the d.b.h. errors in 10 years for the two models*

D.b.h. errors (10 years)	Calibration		Validation	
	Original	New	Original	New
Mean	0.02	−0.03	0.13	0.11
Standard deviation	.52	.46	.73	.63
Number of plots	293		822	
Number of trees[1]	7,702		11,182	

[1]*Value for STEMS model.*

Do trees of a given species grow the same in mixed stands as in pure stands or in one forest type as in another? The results for the original model (with an interaction term) has 14 species-forest type combinations representing 477 trees showing definite interactions between trees of one species growing on a different type forest. The STEMS model with no interaction term (7), has only 6 problem combinations for a total of 199 trees out of 11,182 trees. This represents only 1.8 percent of the trees on the validation data base. Hence the STEMS model, even without attempting to account for species interaction, handles it well.

DISCUSSION

Our test results show that one could justify choosing either model because neither is clearly superior (table 2). An indepth evaluation of both models showing strengths and weaknesses is given in Holdaway and Brand (1983). However, the STEMS model does somewhat better in three of the four performance tests. Furthermore, the STEMS model was judged to be clearly preferable on the basis of ease in

1. calibrating and recalibrating the model,
2. understanding the various components of the model,
3. programming the model and understanding the projection program, and
4. adjusting the model for specific user needs.

The original model had some complex parts that were hard to calibrate, understand, or adjust. As Schaeffer (1980) points out, there are tradeoffs in choosing one model over another and "the simplest model which can be acceptably validated is deemed more suitable than the more complex model". Taking all of the above factors into consideration, the new model was recommended and has been included in the newest STEMS system.

CONCLUSION

The realized growth of a tree in a stand of trees can be characterized by the product of a potential growth function and a modifier of the potential. The modifier function (7) we devised adequately describes how this potential growth is reduced due to the social characteristics of a stand. The $[(BAmax-BA)/BA]^{.5}$ term provides for the effect of crowding (or competition). The modifier becomes zero when the maximum basal area (BAmax) is reached for a species. The g function weights the basal area term to account for the stand effect of the average diameter and the f function then adjusts the index according to the relative diameter of each tree in the stand. Because Bo is a species-specific variable, each species in the stand is grown separately.

Our proposed model performs well for a wide range of Lake States species. It does slightly better than the earlier stand component modifier and is also a simpler, more flexible model.

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The modifier function used in STEMS (Stand and Tree Evaluation and Modeling System) mathematically represents the effect that the surrounding forest community has on the growth of an individual tree. This paper 1) develops the most recent modifier function, 2) discusses its form, 3) reports the results of the analysis with biological considerations, and 4) evaluates the performance of this new model.

KEY WORDS: growth model, competition, projection system, forest growth, Lake States species

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Green Weight Tables for Eight Tree Species in Northern Michigan

Helmuth M. Steinhilb, Rodger A. Arola and Sharon A. Winsauer

ASPEN SUGAR MAPLE
WHITE SPRUCE RED OAK
RED PINE RED MAPLE
BALSAM FIR WHITE BIRCH

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, MN 55108
Manuscript approved for publication February 15, 1984
September 1984

GREEN WEIGHT TABLES FOR EIGHT TREE SPECIES IN NORTHERN MICHIGAN

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Houghton, Michigan

During the last 10 to 15 years utilization of logging residue from merchantable trees and whole-tree chipping of pole-sized trees for fuel and fiber has increased. When logging residue and trees are harvested in chip form, they are usually sold on a green weight basis. Therefore, it has become necessary to develop green weight tables for trees, boles, and residues to enable preharvesting estimates to be made of the material to be removed from the forest.

Between 1966 and 1981, the USDA Forest Service's Forestry Sciences Laboratory, Houghton, Michigan, collected field data and prepared weight tables for eight tree species common to the Upper Peninsula of Michigan (Steinhilb and Erickson 1970, 1972; Steinhilb and Winsauer 1976; Winsauer and Steinhilb 1980; Steinhilb *et al.* in prep.). This publication summarizes these Michigan tables in a uniform and convenient form for use by foresters, loggers, and others concerned with estimating the green weights of trees and tree components. The tables and equations presented estimate the green weights of the tree, bole, and residue for the following species:

trembling aspen *(Populus tremuloides)*,
sugar maple *(Acer saccharum)*,
red maple *(Acer rubrum)*,
white birch *(Betula papyrifera)*,
red oak *(Quercus rubra)*,
red pine *(Pinus resinosa)*,
white spruce *(Picea glauca)*,
balsam fir *(Abies balsamea)*.

DEFINITIONS

The following terms and definitions are used in this publication:

Diameter breast height (d.b.h.)—The diameter of the tree (in inches outside the bark) measured at a point 4-½ feet above the ground.

Tree height—The height of the tree (in feet) from the cut stump to the tip.

Tree weight—The green weight (in pounds) of the entire tree—wood, bark, limbs, and foliage—above the cut stump.

Bole height—The height of the tree bole (in feet) from the cut stump to a point on the main stem at which the diameter outside the bark is 3.0 inches for aspen, red pine, white spruce, and balsam fir and 4.0 inches for sugar maple, red maple, white birch, and red oak. Sawtimber-sized sugar maple were also measured to a point on the main stem to a top diameter inside the bark determined by the uppermost merchantable saw log.

Bole weight—The green weight (in pounds) of the delimbed bole including wood and bark.

Residue weight—The green weight (in pounds) of wood, bark, and foliage of the total tree above the stump, minus the bole weight.

FIELD DATA COLLECTION

All the sample trees were from within 55 miles of Houghton, Michigan. Sample trees were selected to include an approximately equal number of trees in each diameter class. D.b.h. of each tree was measured to the nearest 0.1-inch. The tree was then felled, being careful to minimize breakage and loss of limbs. After felling, tree and bole height were measured to the nearest foot.

Within 24 hours after felling, the entire above-stump portion of each pulpwood tree was weighed by

suspending it from a weight transducer or load cell attached to a hydraulic knuckle boom loader, fork lift, or other lifting device. The tree was then lowered to the ground, the top and limbs were cut off, and the delimbed bole was suspended and weighed.

Sugar maple saw log trees were cut into saw logs to a top diameter of not less than 9.6 inches inside the bark according to commercial logging practice in the area. The length of each bole section, gross and net Scribner Decimal C scale, and butt and top diameter of each section were recorded. The length of the remaining top or crown beyond the last saw log was also recorded. Each bole section and the top of the tree were suspended from the transducer and weighed. The sum of the lengths of the components was used to determine tree height and merchantable bole height. The weights of the saw logs in a tree were added to determine bole weight, and the weights of the top and branches were added to obtain the above-stump green tree weight.

The range of the field data for the species studied is shown in table 1.

ANALYTIC PROCEDURE

The data for each species were analyzed separately, and regression equations were developed for the green weights of trees, boles, and residue. Sugar maple bole weight data were analyzed separately for pulpwood and saw log trees because bole height was defined differently for each group (4-inch top for pulpwood trees and a top diameter of not less than 9.6 inches inside the bark for saw log trees). However, because the measurements were "compatible" for both pulpwood and saw log trees for green tree weight, the data from both categories of trees were combined to obtain green tree weight tables.

The data in this publication for tree, bole, and residue weight are based on (1) d.b.h. and tree height and (2) d.b.h. and bole height to provide consistency and approximate additivity between the component weight equations. The weight equations were as follows:

green component weight in pounds = $A + B(D^2\ Th)$

and

green component weight in pounds = $A + B(D^2\ Bh)$

where:

$A + B$ = regression coefficients,
D = d.b.h. in inches,
Th = tree height in feet, and
Bh = bole height in feet.

TABLES AND REGRESSION EQUATIONS

The regression equations for green tree, bole, and residue weights based on d.b.h. and tree height, together with standard errors of estimate and number of trees sampled for each species are given in table 2. Those based on d.b.h. and bole height are given in table 3.

Green weights for tree, bole, and residue weights as developed from the equations based on d.b.h. and tree height are given in tables 4 through 12; those based on d.b.h. and bole height are given in tables 13 through 21.

USE OF THE WEIGHT TABLES

The weight tables (tables 4 through 21) can be used to obtain preharvest weight inventories for forest stands in the same way that volume tables are used to obtain merchantable volume inventories.

Caution should be observed when using the weight tables for stands outside the study area because the tables were constructed from a limited sample of trees in a local area of Upper Michigan. The best estimates of biomass will result when the tables are used for stands similar in tree size, composition, age, and site index to those from which the sample trees were selected.

LITERATURE CITED

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TABLES

ble 1.--Data range of field tree measurements

ecies	D.b.h.	Tree height	Tree weight	Bole height	Bole weight	Observations
	Inches	Feet	Pounds	Feet	Pounds	Number
pen	5.3-17.4	28-77	80-3,080	17-59	50-2,600	96
ite spruce	6.2-16.2	31-72	255-3,292	22-64	135-2,526	60
d pine	5.6-14.0	47-75	284-2,562	36-64	245-2,122	60
lsam fir	5-0-13.2	31-62	225-2,255	17-54	135-1,700	69
gar maple						
All trees	5.0-24.0	38-89	164-9,016			130
Pulp trees	5.0-11.6	38-72	164-1,677	12-59	87-1,257	54
Saw log trees	11.6-24.0	56-89	1,494-9,016	13-56	582-5,371	76
d oak	3.4-17.1	25-74	60-4,738	10-60	86-2,956	36
d maple	2.0-16.8	22-81	30-4,352	7-67	53-3,163	48
ite birch	1.6-15.6	22-85	5-3,190	3-58	25-2,258	33

Table 2.--Regression equations for determining green weight (in pounds) based on D^2 Th

Species	Regression equation	S.E.E.	Observations	Table number
			Number	
	Green tree weight			
Aspen	23.8 + 0.158 D^2 Th	1.29 D^2	96	4
White spruce	152.7 + 0.161 D^2 Th	2.35 D^2	60	5
Red pine	7.3 + 0.180 D^2 Th	0.76 D^2	60	6
Balsam fir	73.7 + 0.172 D^2 Th	1.81 D^2	69	7
Sugar maple	26.2 + 0.168 D^2 Th	1.56 D^2	130	8
Red oak	2.7 + 0.198 D^2 Th	1.18 D^2	36	10
Red maple	19.9 + 0.164 D^2 Th	1.45 D^2	48	11
White birch	8.7 + 0.173 D^2 Th	1.91 D^2	33	12
	Green bole weight			
Aspen	- 2.0 + 0.128 D^2 Th	0.98 D^2	96	4
White spruce	87.5 + 0.116 D^2 Th	1.51 D^2	60	5
Red pine	10.3 + 0.154 D^2 Th	0.67 D^2	60	6
Balsam fir	14.3 + 0.127 D^2 Th	1.22 D^2	69	7
Sugar maple (pulpwood)	- 78.0 + 0.146 D^2 Th	0.70 D^2	54	8
Sugar maple (saw log)	- 283.4 + 0.116 D^2 Th	1.07 D^2	76	9
Red oak	- 28.0 + 0.158 D^2 Th	0.85 D^2	34	10
Red maple	- 16.8 + 0.127 D^2 Th	0.87 D^2	30	11
White birch	- 35.9 + 0.137 D^2 Th	0.93 D^2	25	12
	Green residue weight			
Aspen	25.8 + 0.030 D^2 Th	0.94 D^2	96	4
White spruce	65.2 + 0.045 D^2 Th	1.64 D^2	60	5
Red pine	- 3.0 + 0.026 D^2 Th	0.40 D^2	60	6
Balsam fir	59.4 + 0.045 D^2 Th	1.32 D^2	69	7
Sugar maple (pulpwood)	65.8 + 0.036 D^2 Th	0.82 D^2	50	8
Sugar maple (saw log)	502.6 + 0.041 D^2 Th	1.60 D^2	76	9
Red oak	19.0 + 0.044 D^2 Th	1.22 D^2	33	10
Red maple	46.2 + 0.034 D^2 Th	1.16 D^2	30	11
White birch	36.2 + 0.038 D^2 Th	1.16 D^2	25	12

Table 3.--Regression equations for determining green weight (in pounds) based on D^2 Bh

Species	Regression equation	S.E.E.	Observations	Table number
			Number	
	Green tree weight			
Aspen	55.5 + 0.204 D^2 Bh	1.35 D^2	96	13
White spruce	215.2 + 0.180 D^2 Bh	2.39 D^2	60	14
Red pine	52.5 + 0.202 D^2 Bh	0.68 D^2	60	15
Balsam fir	155.2 + 0.194 D^2 Bh	1.85 D^2	69	16
Sugar maple (pulpwood)	158.3 + 0.219 D^2 Bh	1.59 D^2	54	17
Sugar maple (sawlog)	1,057.4 + 0.240 D^2 Bh	2.26 D^2	76	18
Red oak	99.0 + 0.256 D^2 Bh	1.51 D^2	33	19
Red maple	107.3 + 0.220 D^2 Bh	1.23 D^2	30	20
White birch	91.0 + 0.228 D^2 Bh	1.44 D^2	25	21
	Green bole weight			
Aspen	21.7 + 0.165 D^2 Bh	0.91 D^2	96	13
White spruce	131.2 + 0.130 D^2 Bh	1.52 D^2	60	14
Red pine	48.2 + 0.172 D^2 Bh	0.53 D^2	60	15
Balsam fir	72.7 + 0.144 D^2 Bh	1.21 D^2	69	16
Sugar maple (pulpwood)	44.8 + 0.184 D^2 Bh	0.51 D^2	54	17
Sugar maple (saw log)	239.2 + 0.189 D^2 Bh	0.72 D^2	76	18
Red oak	53.2 + 0.204 D^2 Bh	0.95 D^2	34	19
Red maple	44.3 + 0.174 D^2 Bh	0.66 D^2	30	20
White birch	34.4 + 0.179 D^2 Bh	0.71 D^2	25	21
	Green residue weight			
Aspen	33.8 + 0.038 D^2 Bh	0.97 D^2	96	13
White spruce	83.9 + 0.050 D^2 Bh	1.66 D^2	60	14
Red pine	4.25 + 0.029 D^2 Bh	0.42 D^2	60	15
Balsam fir	82.6 + 0.050 D^2 Bh	1.34 D^2	69	16
Sugar maple (pulpwood)	95.4 + 0.045 D^2 Bh	0.85 D^2	50	17
Sugar maple (saw log)	818.2 + 0.050 D^2 Bh	1.81 D^2	76	18
Red oak	42.9 + 0.055 D^2 Bh	1.27 D^2	33	19
Red maple	63.0 + 0.046 D^2 Bh	1.17 D^2	30	20
White birch	56.7 + 0.049 D^2 Bh	1.21 D^2	25	21

Table 4.--Trembling aspen green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80	90
				Green tree weight				
4	74	100	125	150	175	201		
6	138	194	251	308	365	422	479	536
8	226	327	428	529	631	732	833	934
10	340	498	656	814	972	1,130	1,288	1,446
12	479	706	934	1,161	1,389	1,616	1,844	2,071
14		953	1,263	1,572	1,882	2,192	2,501	2,811
16			1,642	2,046	2,451	2,855	3,260	3,664
18				2,583	3,095	3,607	4,119	4,631
20				3,184	3,816	4,448	5,080	5,712
				Green bole weight				
6	90	136	182	228	274	321	367	413
8	162	244	326	408	490	571	653	735
10	254	382	510	638	766	894	1,022	1,150
12	367	551	735	920	1,104	1,288	1,473	1,657
14		751	1,002	1,252	1,503	1,754	2,005	2,256
16			1,309	1,636	1,964	2,292	2,619	2,947
18				2,072	2,486	2,901	3,316	3,730
20				2,558	3,070	3,582	4,094	4,606
				Green residue weight				
6	47	58	69	80	91	101	112	123
8	64	83	103	122	141	160	179	199
10	86	116	146	176	206	236	266	296
12	112	155	199	242	285	328	371	415
14		202	261	320	379	437	496	555
16			333	410	487	563	640	717
18				512	609	706	803	901
20				626	746	866	986	1,106

Table 5.--White spruce green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
				Green tree weight			
4	204	230	256	282	307	333	
6	269	327	385	443	500	558	616
8	359	462	565	668	771	874	977
10	475	636	797	958	1,119	1,280	1,441
12		848	1,080	1,312	1,544	1,776	2,007
14		1,099	1,415	1,731	2,046	2,362	2,677
16			1,801	2,214	2,626	3,038	3,450
18				2,761	3,283	3,804	4,326
20					4,017	4,661	5,305
				Green bole weight			
6	171	213	255	296	338	380	422
8	236	310	384	459	533	607	681
10	320	436	552	668	784	900	1,016
12		589	756	923	1,090	1,257	1,424
14		770	997	1,224	1,452	1,679	1,906
16			1,275	1,572	1,869	2,166	2,463
18				1,967	2,343	2,718	3,094
20					2,872	3,336	3,800
				Green residue weight			
6	98	114	130	146	162	179	195
8	123	152	180	209	238	267	296
10	155	200	245	290	335	380	425
12		260	324	389	454	519	584
14		330	418	506	594	683	771
16			526	641	756	872	987
18				794	940	1,086	1,232
20					1,145	1,325	1,505

Table 6.--Red pine green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
				Green tree weight			
4		94	123	151	180	209	238
6		202	267	331	396	461	526
8		353	468	583	699	814	929
10		547	727	907	1,087	1,267	1,447
12		785	1,044	1,303	1,563	1,822	2,081
14				1,771	2,124	2,477	2,830
16				2,311	2,772	3,233	3,694
18					3,507	4,090	4,673
20						5,057	5,767
				Green bole weight			
6		177	232	288	343	398	454
8		306	405	503	602	700	799
10		472	626	780	934	1,088	1,242
12		676	897	1,119	1,341	1,563	1,784
14		916	1,218	1,520	1,821	2,123	2,425
16				1,982	2,376	2,770	3,164
18					3,004	3,503	4,002
20						4,322	4,938
				Green residue weight			
6		25	34	44	53	63	72
8		47	64	80	97	113	130
10		75	101	127	153	179	205
12		109	147	184	222	259	297
14		150	201	252	303	354	405
16				330	396	463	529
18					502	587	671
20						725	829

Table 7.--Balsam fir green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
				Green tree weight			
4	129	156	184	211	239		
6	198	259	321	383	445	507	
8	294	404	514	624	734	844	954
10	418	590	762	934	1,106	1,278	1,450
12	569	817	1,064	1,312	1,560	1,807	2,055
14	748	1,085	1,422	1,759	2,096	2,434	2,771
16		1,395	1,835	2,275	2,716	3,156	3,596
18				2,860	3,417	3,975	4,532
20					4,202	4,890	5,578
				Green bole weight			
6	106	151	197	243	289	334	380
8	177	258	339	421	502	583	665
10	268	395	522	649	776	903	1,030
12	380	563	746	929	1,112	1,294	1,477
14	512	761	1,010	1,259	1,508	1,757	2,006
16		990	1,315	1,640	1,965	2,290	2,615
18				2,072	2,483	2,895	3,306
20					3,062	3,570	4,078
				Green residue weight			
6	92	108	124	140	157	173	189
8	117	146	175	203	232	261	290
10	149	194	239	284	329	374	419
12	189	254	319	383	448	513	578
14	236	324	412	500	589	677	765
16		405	520	635	751	866	981
18				788	934	1,080	1,226
20					1,139	1,319	1,499

Table 8.--Sugar maple pulpwood green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (all trees) 20	30	40	50	60	70	80	90
				Green tree weight (all trees)				
4		107	134	161	187	214	241	
6		208	268	329	389	450	510	571
8		349	456	564	671	779	886	994
10		530	698	866	1,034	1,202	1,370	1,538
12		752	994	1,236	1,478	1,720	1,962	2,203
14			1,343	1,673	2,002	2,331	2,660	2,990
16			1,747	2,177	2,607	3,037	3,467	3,997
18			2,203	2,748	3,292	3,836	4,381	4,925
20				3,386	4,058	4,730	5,402	6,074
22				4,092	4,905	5,718	6,531	7,344
24				4,865	5,832	6,800	7,768	8,735
26					6,840	7,976	9,112	10,247
				Green bole weight (pulpwood trees)				
6		80	132	185	237	290	342	
8		202	296	389	483	576	670	
10		360	506	652	798	944	1,090	
12		553	763	973	1,183	1,394	1,604	
14		780	1,067	1,353	1,639	1,925	2,211	
16			1,417	1,791	2,165	2,538	2,912	
18				2,287	2,760	3,233	3,706	
				Green residue weight (pulpwood trees)				
6		105	118	131	144	157	169	
8		135	158	181	204	227	250	
10		174	210	246	282	318	354	
12		221	273	325	377	429	481	
14		277	348	419	489	560	630	
16			434	527	619	711	803	
18				649	766	882	999	

Table 9.--Sugar maple saw log green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 40	50	60	70	80	90
			Green bole weights (saw log trees)			
12	385	552	719	886	1,053	1,220
14	626	853	1,081	1,308	1,535	1,763
16	904	1,201	1,498	1,795	2,092	2,389
18	1,220	1,596	1,972	2,347	2,723	3,099
20	1,573	2,037	2,501	2,965	3,429	3,893
22	1,962	2,524	3,085	3,647	4,208	4,770
24		3,057	3,726	4,394	5,062	5,730
26			4,422	5,206	5,990	6,774
			Green residue weights (saw log trees)			
12	739	798	857	916	975	1,034
14	824	904	985	1,065	1,145	1,226
16	922	1,027	1,132	1,237	1,342	1,447
18	1,034	1,167	1,300	1,432	1,565	1,698
20	1,159	1,323	1,487	1,651	1,815	1,979
22	1,296	1,495	1,693	1,892	2,090	2,289
24		1,683	1,920	2,156	2,392	2,628
26			2,166	2,443	2,720	2,997

Table 10.--Red oak green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
				Green tree weight			
2	19	26	34	42	50		
4	66	98	129	161	193	224	
6	145	217	288	359	430	502	573
8		383	510	636	763	890	1,016
10		597	795	993	1,191	1,389	1,587
12			1,143	1,428	1,713	1,999	2,284
14			1,555	1,943	2,331	2,719	3,107
16			2,030	2,537	3,044	3,551	4,058
18			2,569	3,210	3,852	4,493	5,135
20				3,963	4,755	5,547	6,339
				Green bole weight			
6		143	200	256	313	370	
8		275	376	478	579	680	781
10		446	604	762	920	1,078	1,236
12			882	1,110	1,337	1,565	1,792
14			1,211	1,520	1,830	2,140	2,449
16			1,590	1,994	2,399	2,803	3,208
18			2,020	2,532	3,044	3,555	4,067
20			2,500	3,132	3,764	4,396	5,028
				Green residue weight			
6		67	82	98	114	130	
8		103	132	160	188	216	244
10		151	195	239	283	327	371
12			272	336	399	463	526
14			364	450	536	623	709
16			470	582	695	807	920
18			589	732	874	1,017	1,159
20			723	899	1,075	1,251	1,427

Table 11.--Red maple green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
			Green tree weight				
2	33	40	46	53	59		
4	72	99	125	151	177		
6	138	197	256	315	374	433	492
8	230	335	440	545	650	755	860
10	348	512	676	840	1,004	1,168	1,332
12		728	965	1,201	1,437	1,673	1,909
14		984	1,306	1,627	1,949	2,270	2,591
16			1,699	2,119	2,539	2,959	3,379
18				2,677	3,208	3,739	4,271
20				3,300	3,956	4,612	5,268
			Green bole weight				
6		120	166	212	258	303	
8		227	308	390	471	552	633
10		364	491	618	745	872	999
12		532	715	898	1,080	1,263	1,446
14			979	1,228	1,477	1,726	1,975
16			1,284	1,609	1,934	2,259	2,584
18				2,041	2,452	2,864	3,275
20				2,523	3,031	3,539	4,047
			Green residue weight				
6		83	95	107	120	132	
8		111	133	155	177	199	220
10		148	182	216	250	284	318
12		193	242	291	340	389	438
14			313	379	446	513	579
16			394	481	568	655	743
18				597	707	817	927
20					862	998	1,134

Table 12.--White birch green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Tree height (feet) 20	30	40	50	60	70	80
			Green tree weight				
2	23	29	36	43	50		
4	64	92	119	147	175		
6	133	196	258	320	382	445	507
8	230	341	452	562	673	784	894
10	355	528	701	874	1,047	1,220	1,393
12		756	1,005	1,254	1,503	1,753	2,002
14		1,026	1,365	1,704	2,043	2,382	2,721
16		1,337	1,780	2,223	2,666	3,109	3,552
18			2,251	2,811	3,372	3,932	4,493
20				3,469	4,161	4,853	5,545
			Green bole weight				
6		112	161	211	260	309	
8		227	315	403	490	578	
10		375	512	649	786	923	1,060
12		556	753	951	1,148	1,345	1,542
14		770	1,038	1,307	1,575	1,844	2,112
16			1,367	1,718	2,068	2,419	2,770
18			1,740	2,184	2,627	3,017	3,515
20			2,156	2,704	3,252	3,800	4,348
			Green residue weight				
6		77	91	105	118	132	
8		109	133	158	182	206	231
10		150	188	226	264	302	340
12		200	255	310	365	419	474
14			334	409	483	558	632
16			425	523	620	717	814
18			529	652	775	898	1,021
20			644	796	948	1,100	1,252

Table 13.--Aspen green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	83	110	137	164	192			
6	117	178	239	300	362	423		
8	164	273	382	491	600	708	817	926
10	225	396	566	735	906	1,076	1,245	1,416
12	330	545	790	1,035	1,280	1,524	1,769	2,014
14		722	1,055	1,388	1,722	2,055	2,388	2,721
16			1,361	1,796	2,232	2,667	3,102	3,537
18				2,558	2,810	3,360	3,911	4,462
20					3,456	4,136	4,815	5,496
				Green bole weight				
6	71	121	170	220	269	319		
8	110	198	286	374	462	550	638	726
10	159	297	434	572	709	847	984	1,122
12	220	418	616	814	1,012	1,210	1,408	1,606
14		561	830	1,100	1,369	1,639	1,908	2,178
16			1,078	1,430	1,782	2,134	2,486	2,838
18				1,804	2,249	2,695	3,140	3,586
20					2,772	3,322	3,871	4,422
				Green residue weight				
6	45	57	68	79	91	102		
8	54	74	95	115	135	155	176	196
10	65	97	129	160	192	224	255	287
12	79	125	171	216	262	307	353	399
14		158	220	282	344	406	469	530
16			277	358	439	520	601	682
18				444	547	649	752	855
20					667	794	920	1,047

Table 14.--White spruce green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	239	263	287	311	335	359		
6	269	323	377	431	485	539	593	647
8	311	407	503	599	695	791	887	983
10	365	515	665	815	965	1,115	1,265	1,415
12		647	863	1,079	1,295	1,511	1,727	1,943
14		803	1,097	1,391	1,685	1,979	2,273	2,567
16			1,367	1,751	2,135	2,519	2,903	3,287
18				2,159	2,645	3,131	3,617	4,103
20					3,215	3,815	4,415	5,015
				Green bole weight				
6	170	209	248	287	326	365	404	443
8	201	270	339	409	478	547	617	686
10	239	348	456	564	673	781	889	998
12	287	443	599	755	911	1,067	1,223	1,379
14		556	768	980	1,193	1,405	1,617	1,830
16			963	1,240	1,518	1,795	2,072	2,350
18				1,535	1,886	2,237	2,588	2,939
20					2,298	2,731	3,164	3,598
				Green residue weight				
6	99	114	129	144	159	174	189	204
8	111	137	164	191	217	244	271	297
10	126	167	209	251	292	334	376	417
12	144	204	264	324	384	444	504	564
14		247	329	411	492	574	656	737
16			404	511	617	724	831	937
18				624	759	894	1,029	1,164
20					917	1,084	1,251	1,417

Table 15.--Red pine green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 2	3	4	5	6	7	8	9
				Green tree weight				
4	106	133	160	187	214	241		
6	174	234	295	356	416	477	537	
8	268	376	483	591	699	807	914	1,022
10	389	558	726	894	1,063	1,231	1,399	1,567
12	537	780	1,022	1,265	1,507	1,749	1,992	2,234
14			1,372	1,702	2,032	2,362	2,692	3,022
16				2,207	2,638	3,069	3,500	3,931
18					3,325	3,870	4,416	4,961
20					4,093	4,766	5,439	6,112
				Green bole weight				
6	151	203	255	306	358	409	461	
8	232	323	415	507	599	690	782	874
10	335	478	621	765	908	1,051	1,195	1,339
12	461	667	874	1,080	1,287	1,493	1,699	1,906
14			1,172	1,453	1,734	2,015	2,296	2,577
16				1,883	2,250	2,617	2,984	3,351
18					2,835	3,299	3,764	4,228
20					3,488	4,061	4,635	5,208
				Green residue weight				
6	22	30	39	48	56	65	74	
8	35	51	66	82	97	113	128	143
10	53	77	101	125	149	173	198	222
12	74	109	143	178	213	248	283	317
14			194	241	288	336	383	431
16				314	375	437	499	561
18					474	552	631	709
20					584	681	778	874

Table 16.--Balsam fir green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	181	207	233	259	285			
6	213	272	330	388	446	504		
8	259	362	466	569	673	776	879	983
10	317	479	640	802	964	1,125	1,287	1,449
12	388	621	854	1,086	1,319	1,552	1,785	2,018
14		789	1,106	1,423	1,740	2,056	2,373	2,690
16			1,397	1,811	2,225	2,638	3,052	3,466
18				2,250	2,774	3,298	3,822	4,346
20					3,389	4,035	4,683	5,329
				Green bole weight				
6	116	159	202	245	289	332		
8	149	226	303	380	457	534	610	687
10	193	313	433	553	673	793	913	1,033
12	245	418	591	764	937	1,110	1,282	1455
14		543	778	1,013	1,249	1,484	1,719	1,954
16			994	1,301	1,609	1,916	2,223	2,530
18				1,628	2,017	2,406	2,794	3,183
20					2,473	2,953	3,433	3,913
				Green residue weight				
6	98	113	128	143	158	173		
8	109	136	163	189	216	243	269	296
10	124	166	208	249	291	333	374	416
12	143	203	263	323	383	443	503	563
14		246	328	409	491	573	654	736
16			403	509	616	723	829	936
18				623	758	893	1,028	1,163
20					916	1,083	1,249	1,416

Table 17.--Sugar maple pulpwood green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts to 4-inch top) 1	2	3	4	5	6	7	8
				Green tree weight				
4	187	217	246	275	304			
6	224	290	355	421	487	553		
8	275	392	509	625	742	859	976	
10	341	523	706	888	1,071	1,253	1,436	1,618
12	421	684	947	1,209	1,472	1,735	1,998	2,261
14		874	1,231	1,589	1,947	2,305	2,662	3,020
16			1,560	2,027	2,494	2,962	3,429	3,896
18				2,523	3,115	3,706	4,297	4,889
20					3,809	4,538	5,268	5,999
				Green bole weight				
6	100	155	210	266	321	376		
8	143	241	339	437	536	634	732	
10	198	352	505	658	812	965	1,118	1,272
12	266	286	707	928	1,149	1,370	1,590	1,811
14		646	946	1,247	1,548	1,848	2,148	2,449
16			1,222	1,615	2,008	2,400	2,792	3,185
18				2,032	2,529	3,026	3,522	4,019
20					3,112	3,725	4,338	4,952
				Green residue weight				
6	109	122	136	149	163	176		
8	119	143	167	191	215	239	263	
10	133	170	208	245	283	320	358	395
12	149	203	257	311	365	419	473	527
14		242	316	389	463	536	610	683
16			383	479	575	671	767	863
18				581	703	824	946	1,067
20					845	995	1,145	1,295

Table 18.--Sugar maple sawtimber green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. classs (inches)	Bole height (number of 100-inch bolts to variable top) 1	2	3	4	5	6	7	8
	Green tree weight							
12	1,345	1,634	1,921	2,209	2,498			
14	1,449	1,842	2,233	2,625	3,018	3,409	3,801	
16	1,569	2,082	2,593	3,105	3,618	4,129	4,641	5,154
18	1,705	2,354	3,001	3,649	4,298	4,945	5,593	6,242
20		2,658	3,457	4,257	5,058	5,857	6,657	7,458
22		2,994	3,961	4,929	5,898	6,865	7,833	8,802
24			4,513	5,665	6,818	7,969	9,121	10,274
26			5,113	6,465	7,818	9,169	10,521	11,874
	Green bole weight							
12	466	693	920	1,146	1,373			
14	548	857	1,165	1,474	1,783	2,091	2,400	
16	642	1,046	1,449	1,852	2,255	2,658	3,061	3,465
18	749	1,260	1,770	2,280	2,791	3,301	3,811	4,322
20		1,499	2,129	2,759	3,389	4,019	4,649	5,279
22		1,764	2,526	3,288	4,051	4,813	5,575	6,338
24			2,961	3,868	4,776	5,682	6,589	7,497
26			3,433	4,498	5,563	6,627	7,692	8,757
	Green residue weight							
12	878	938	998	1,058	1,118			
14	900	982	1,063	1,145	1,227	1,308	1,390	
16	925	1,032	1,138	1,245	1,352	1,458	1,565	1,672
18	953	1,088	1,223	1,358	1,493	1,628	1,763	1,899
20		1,152	1,318	1,485	1,652	1,818	1,985	2,152
22		1,222	1,423	1,625	1,827	2,028	2,230	2,432
24			1,538	1,778	2,018	2,258	2,498	2,738
26			1,663	1,945	2,227	2,508	2,790	3,072

'able 19.--Red oak green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	133	167	201	236	270	304	338	
6	176	253	329	406	483	560	637	713
8	235	372	509	645	782	918	1,055	1,191
10	312	526	739	952	1,166	1,379	1,592	1,806
12	406	714	1,021	1,328	1,635	1,942	2,249	2,557
14		935	1,353	1,771	2,190	2,608	3,026	3,444
16			1,737	2,283	2,830	3,376	3,922	4,468
18				2,864	3,555	4,246	4,937	5,629
20					4,366	5,219	6,072	6,926
				Green bole weight				
6	114	176	237	298	359	420	482	
8	162	271	380	488	597	706	815	924
10	223	393	563	733	903	1,073	1,243	1,413
12	298	543	788	1,032	1,277	1,522	1,767	2,012
14		720	1,053	1,386	1,719	2,052	2,385	2,719
16			1,359	1,794	2,229	2,664	3,099	3,535
18				2,256	2,807	3,358	3,909	4,460
20					3,453	4,133	4,813	5,493
				Green residue weight				
6	59	76	92	109	125	142	158	
8	72	102	131	160	190	219	248	278
10	89	135	180	226	272	318	364	410
12	109	175	241	307	373	439	505	571
14		223	312	402	492	582	672	762
16			395	512	630	747	864	982
18				637	785	934	1,082	1,231
20					960	1,143	1,326	1,510

Table 20.--Red maple green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	137	166	195	225	254	283	313	
6	173	239	305	371	437	503	569	635
8	225	342	459	577	694	811	929	1,046
10	291	474	657	841	1,024	1,207	1,391	1,574
12		635	899	1,163	1,427	1,691	1,955	2,219
14		826	1,185	1,544	1,904	2,263	2,622	2,982
16				1,984	2,454	2,923	3,392	3,862
18				2,483	3,078	3,671	4,265	4,860
20					3,774	4,507	5,240	5,974
				Green bole weight				
6	96	149	201	253	305	358	410	
8	137	230	323	415	508	601	694	787
10	189	334	479	624	769	914	1,059	1,204
12		462	671	879	1,088	1,297	1,506	1,715
14		613	897	1,181	1,465	1,750	2,034	2,318
16				1,529	1,900	2,272	2,643	3,014
18				1,923	2,393	2,863	3,333	3,803
20					2,945	3,524	4,104	4,685
				Green residue weight				
6	77	91	104	118	132	146	160	
8	88	112	137	161	186	210	235	259
10	101	140	178	216	255	293	331	370
12		173	229	284	339	394	449	505
14		213	288	364	439	514	589	664
16				455	554	652	750	848
18				560	684	808	932	1,057
20					830	983	1,136	1,290

Table 21.--White birch green weights (values inside the lines show the range of the sample data)

(In pounds)

D.b.h. class (inches)	Bole height (number of 100-inch bolts) 1	2	3	4	5	6	7	8
				Green tree weight				
4	121	152	182	213	243	273		
6	159	228	296	365	433	501	570	
8	213	334	456	577	699	821	942	1,064
10	281	471	661	851	1,041	1,231	1,421	1,611
12	364	638	912	1,185	1,459	1,733	2,006	2,280
14			1,208	1,581	1,953	2,325	2,698	3,070
16				2,037	2,523	3,009	3,496	3,982
18					3,169	3,785	4,400	5,016
20					3,891	4,651	5,411	6,171
				Green bole weight				
6	88	142	196	249	303	357	410	
8	130	225	321	416	512	607	703	798
10	184	333	482	631	780	929	1,079	1,228
12	249	464	679	894	1,108	1,323	1,538	1,753
14			912	1,204	1,496	1,789	2,081	2,373
16				1,562	1,944	2,326	2,707	3,089
18					2,451	2,934	3,417	3,901
20					3,018	3,614	4,211	4,808
				Green residue weight				
6	71	86	101	115	130	145	160	
8	83	109	135	161	187	214	240	266
10	98	138	179	220	261	302	343	383
12	115	174	233	292	351	410	468	527
14			297	377	457	537	617	697
16				475	579	684	788	893
18					718	851	983	1,115
20					873	1,037	1,200	1,363

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Presents the green weights of the above-stump portions of trees, boles, and residue for eight tree species in northern Michigan. Estimating equations and weight tables are presented for the tree components of each species.

KEY WORDS: Trembling aspen, sugar maple, red maple, white birch, red oak, red pine, white spruce, balsam fir.

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Empirical Yield Tables for Michigan

Jerold T. Hahn and Joan M. Stelman

- White pine
- Red pine
- Jack pine
- White spruce
- Black spruce
- Balsam fir
- Hemlock
- Tamarack
- White cedar
- White oak
- Red oak
- Hickory
- Yellow birch
- Hard maple
- Soft maple
- Beech
- Ash
- Balsam poplar
- Cottonwood
- Bigtooth aspen
- Quaking aspen
- Basswood
- Yellow poplar
- Black walnut
- Black cherry
- Butternut
- Elm
- Paper birch

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CONTENTS

EMPIRICAL YIELD TABLES FOR MICHIGAN

Jerold T. Hahn, *Principal Mensurationist,*
and **Joan M. Stelman,** *Statistical Assistant*

Empirical yield tables are useful to managers of timber, wildlife, and other forest resources who are interested in estimating current commercial forest species composition and volume or in making rough, short-term projections of future conditions. This paper provides empirical yield tables for Michigan and demonstrates some uses for them. If you are interested in comparing conditions in the Lake States, similar sets of tables are presented in "Empirical Yield Tables for Wisconsin" (Essex and Hahn 1976) and "Empirical Yield Tables for Minnesota" (Hahn and Raile 1982). In addition, unpublished empirical yield tables for Missouri and Iowa are available at cost from the Forest Inventory and Analysis Research Work Unit at the North Central Forest Experiment Station.

Yield tables for Michigan were compiled from data gathered on 7,700 commercial forest land plots established during the 1980 inventory of Michigan's four Forest Survey Units (fig. 1). Tables by forest type and site index class are presented for the entire State and for each Survey Unit. Only tables having sufficient data, usually 3 or 4 plots, in each of three adjacent age classes are presented; we feel that information based on smaller samples would not be useful. In addition to the net cubic foot volume tables, we present tables showing total green weight of above-ground biomass for all live trees. State total tables for all sites are printed in this report. State total tables by site index class and Survey Unit tables are included as microfiche inside the back cover.

The tables give the estimated merchantable cubic foot volume yield per acre from growing-stock trees[1] and the average basal area per acre of all live trees 1.0 inches diameter breast height (d.b.h.) and larger by stand age class for the 14 forest types defined in the Appendix. These tables provide a detailed picture of stand composition as measured by growing-stock volume.

[1] *See Appendix for definitions of growing-stock and all live trees.*

The tables were constructed by classifying the commercial forest land plots measured in the 1980 inventory by forest type, stand-age class, and site-index class. Then the per-acre merchantable cubic foot volume or the total above-ground biomass was tabulated by species group. The merchantable volume standards used are minimum 5-inch (d.b.h.) to a 4-inch top diameter outside bark (top d.o.b.) with a 1 foot stump. Individual tree volumes were computed using a formula developed from "Composite volume tables for timber and their application in the Lake States" (Gevorkiantz and Olsen 1955) as described by Raile *et al.* (1982). A full explanation of the survey procedures and definitions can be obtained from "Michigan Forest Statistics, 1980" (Raile and Smith 1983).

The tables can be used in several ways. For example, they can be used to estimate future timber yield in the same manner as normal yield tables—it is assumed that the volume shown in one age class will increase in 10 years to the volume shown in the next older age class. For example, red pine stands aged 61-70 years currently average 1,425 cubic feet per acre (table 2). If you have a stand of red pine 51-60 years old, you could expect that in 10 years the stand would yield approximately 1,425 cubic feet per acre.

Rotation age (Years)	Area harvested year[2] *(Thousand acres)*		Merchantable volume/ acre[3] *(Cubic feet)*		Annual harvest volume *(Million cubic feet)*
35	97.3	X	978	=	95.1
45	75.7	X	1,136	=	86.0
55	61.9	x	1,252	=	77.5

[2] *Total type acreage (3,406,600 acres)/rotation age (35 years).*

[3] *From table 13.*

Figure 1. *Forest Survey Units* *Michigan.*

As a second example, these tables can be used in conjunction with other forest inventory publications to compare volume estimates for progressive rotation ages. For instance, the aspen type occupied 3,406,600 acres in Michigan in 1980 (Spencer 1983). Assuming that you would harvest an equal number of acres each year, estimates of the annual harvest volume can be derived using the yields shown in table 13.

In addition, these harvest volumes can be broken down by species group. (See Appendix for a detailed breakdown of the species groups). By using table 13, the annual harvest volume is further broken down into softwoods and hardwoods.

According to this analysis, both the greatest total yield and the greatest softwood yield would be attained by using a 35-year rotation for the aspen type, although more acres would have to be harvested each

Rotation age (Years)	Total	Harvest volume Softwoods	Hardwood
		(Million cubic feet)	
35	95.1	12.9[4]	82.2
45	86.0	12.8	73.2
55	77.5	12.2	65.3

year to obtain that volume. Currently, almost tw thirds of the plots in the aspen type are in stands old than 35 years. Therefore, considerable volume fro older plots would have to be harvested to reach a 3 year rotation.

[4]*Cubic feet/acre of softwoods or hardwoods in t forest type of interest (133 cubic feet) x number of ac in the forest type (97,300 acres.)*

Finally, the basal area volume in these tables allow ι comparison between stand density and stand age hat can be used in conjunction with other inventory lata to determine whether existing stands are fully tocked. For example, in 1980 there were 481.3 thou-and acres of aspen 51-60 years old in Michigan Spencer 1983). Yields in these stands (all species) ιveraged 98 square feet per acre (table 13). Thus, the atio of volume to basal area was 12.8 to 1. Schlaegel 1971) predicted that such a ratio for fully stocked tands of aspen in Minnesota would be 26 to 1. If we iew Schlaegel's prediction as an index of stand otential, we can generalize that similar aspen sites hat are fully stocked could be expected to yield oughly twice as much as these stands are producing ιow. The comparison can only be approximate because Schlaegel used different standards of merchantability n computing his volume.

The volumes shown in these tables were obtained rom plots located in stands with various histories, rom undisturbed stands to those that had been repeat-dly cut. Thus, standard errors of mean volume are given in the tables to indicate their variation. Sampling rror in percent can be determined by dividing the tandard error by the mean volume of all species. For example, the sampling error for jack pine in the 41-50 ear age class for all sites combined (table 1) is 6.6 percent (53/809) x 100).

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APPENDIX

DEFINITION OF TERMS

Forest type.—A classification of forest land based upon the species forming a plurality of live tree stocking. Major forest types in Michigan are:

Jack pine.—Forests in which jack pine comprise a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple).

Red pine.—Forests in which red pine comprise a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple).

White pine.—Forests in which eastern white pine comprise a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple).

Balsam Fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack).

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack).

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar).

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with

northern white-cedar the most common. (Common associates include tamarack and black spruce).

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar).

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, beech, yellow-poplar, elm, and maple).

Elm-ash-soft maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprimise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir).

Maple-birch.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, and hemlock).

Aspen.—Forests in whch quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch).

Paper birch.—Forests in which paper birch comprise a plurality of the stocking. (Common associates include maple, aspen, and balsam fir).

Exotic.—Forests in which species not native to Michigan comprise a plurality of the stocking. (Most common exotic species is Scotch pine).

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees (excludes rough and rotten trees).

Live trees.—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

TREE SPECIES GROUPS IN MICHIGAN[5]

SOFTWOODS
- Eastern white pine .... *Pinus strobus*
- Red pine .... *Pinus resinosa*
- Jack pine .... *Pinus banksiana*
- White spruce .... *Picea glauca*
- Black spruce .... *Picea mariana*
- Balsam fir .... *Abies balsamea*
- Eastern hemlock .... *Tsuga canadensis*
- Tamarack .... *Larix laricina*
- Northern white-cedar .... *Thuja occidentalis*

[5] *The common and scientific names are based on: Little, Elbert L. Checklist of United States Trees (Native and Naturalized). Agric. Handb. No. 541. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 375 p.*

- Other softwoods
  - Eastern redcedar .... *Juniperus virginiana*
  - Norway spruce .... *Picea abies*
  - Engelmann spruce .... *Picea engelmannii*
  - Austrian pine .... *Pinus nigra*
  - Scotch pine .... *Pinus sylvestris*

HARDWOODS
- White oaks
  - White oak .... *Quercus alba*
  - Swamp white oak .... *Quercus bicolor*
  - Bur oak .... *Quercus macrocarpa*
  - Chinkapin oak .... *Quercus muehlenbergii*
  - Chestnut oak .... *Quercus prinus*
- Select red oak
  - Northern red oak .... *Quercus rubra*
- Other red oaks
  - Scarlet oak .... *Quercus coccinea*
  - Northern pin oak .... *Quercus ellipsoidalis*
  - Pin oak .... *Quercus palustris*
  - Black oak .... *Quercus velutina*
- Hickories
  - Bitternut hickory .... *Carya cordiformis*
  - Pignut hickory .... *Carya glabra*
  - Shellbark hickory .... *Carya laciniosa*
  - Shagbark hickory .... *Carya ovata*
  - Mockernut hickory .... *Carya tomentosa*
- Yellow birch .... *Betula alleghaniensis*
- Hard maples
  - Sugar maple .... *Acer saccharum*
  - Black maple .... *Acer nigrum*
- Soft maples
  - Red maple .... *Acer rubrum*
  - Silver maple .... *Acer saccharinum*
- American beech .... *Fagus grandifolia*
- Ashes
  - White ash .... *Fraxinus americana*
  - Black ash .... *Fraxinus nigra*
  - Green ash .... *Fraxinus pennsylvanica*
- Balsam poplar .... *Populus balsamifera*
- Eastern cottonwood .... *Populus deltoides*
- Aspens
  - Bigtooth aspen .... *Populus grandidentata*
  - Quaking aspen .... *Populus tremuloides*
- Basswood .... *Tilia americana*
- Yellow-poplar .... *Liriodendron tulipifera*
- Black walnut .... *Juglans nigra*
- Black cherry .... *Prunus serotina*
- Butternut .... *Juglans cinerea*
- Elms
  - American elm .... *Ulmus americana*
  - Slippery elm .... *Ulmus rubra*
  - Rock elm .... *Ulmus thomasii*
- Paper birch .... *Betula papyrifera*
- Other hardwoods
  - Boxelder .... *Acer negundo*
  - Sweet birch .... *Betula lenta*

River birch .... *Betula nigra*
Black willow.......................... *Salix nigra*
Ohio buckeye .... *Aesculus glabra*
Flowering dogwood .... *Cornus florida*
Honeylocust................. *Gleditsia triacanthos*
Osage-orange .... *Maclura pomifera*
Black tupelo .... *Nyssa sylvatica var. sylvatica*
Sycamore .... *Platanus occidentalis*
Black locust................ *Robinia pseudoacacia*
Sassafras...................... *Sassafras albidum*
Red mulberry .... *Morus rubra*
American chestnut............ *Castanea dentata*

Table 1.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Jack pine forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	8	10	0	10	13	10	0	21	92	212	0	0
Red pine	48	21	27	31	65	65	41	27	76	99	124	0	0
Jack pine	440	89	139	219	450	633	542	712	644	500	259	480	207
White spruce	0	0	0	0	0	1	2	0	0	0	0	0	0
Black spruce	6	3	0	0	14	5	14	0	6	0	34	0	0
Balsam fir	1	0	0	0	1	2	0	0	3	0	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	1	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	2	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	509	121	176	250	544	719	608	739	750	690	630	480	207
Hardwoods:													
Select white oaks	2	2	0	2	1	1	8	6	0	0	0	0	0
Select red oaks	28	25	16	2	16	51	28	16	40	0	199	240	0
Other red oaks	14	2	0	8	20	14	21	30	26	0	0	0	0
Hickory	0	0	0	0	0	1	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	1	0	0	0	0	0	0	0
Soft maple	4	5	2	0	5	1	2	0	29	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	2	4	0	6	0	4	2	0	0	0	0	0	0
Quaking aspen	9	2	5	4	10	14	13	13	14	0	0	0	0
Basswood	0	0	0	0	0	1	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1	0	0	0	0	0	2	0	0	9	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	1	0	0	0	0	0	0	0
Paper birch	1	0	0	0	1	0	0	0	6	0	37	0	0
Other hardwoods	0	0	0	0	0	1	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	62	40	22	22	54	90	76	65	115	9	236	240	0
All species	571	161	198	272	597	809	684	805	865	699	866	720	207
Number of plots	346	35	40	31	56	76	52	24	21	7	2	1	1
Standard error[3/]	25	30	32	62	52	53	61	99	94	197	52	R	R
Average basal area	65	27	45	59	65	86	75	71	68	70	74	56	30

[1/]Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 2.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Red pine forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	48	8	1	5	5	38	17	267	86	204	290	323	0
Red pine	690	56	181	719	852	882	655	793	980	869	1,332	1,022	605
Jack pine	69	25	13	50	87	189	94	6	136	29	0	85	0
White spruce	6	5	0	1	5	0	0	0	21	0	72	46	0
Black spruce	4	0	0	0	3	8	0	8	0	7	16	32	0
Balsam fir	7	13	0	9	1	0	0	31	0	0	13	32	0
Hemlock	2	0	0	0	0	0	0	49	0	0	0	0	0
Tamarack	1	0	0	0	4	0	0	0	0	0	0	0	0
Northern white-cedar	2	0	0	1	4	0	0	6	0	0	0	16	0
Other softwoods	5	0	12	2	7	0	0	45	0	0	0	0	0
Total	833	107	208	789	968	1,117	765	1,205	1,223	1,111	1,724	1,557	605
Hardwoods:													
Select white oaks	9	0	6	9	20	12	21	0	8	0	0	0	0
Select red oaks	22	0	9	3	15	39	41	30	27	143	91	75	0
Other red oaks	11	0	0	11	27	7	0	0	0	0	0	44	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	3	0	5	6	0	0	0	10	0	0	0	0	0
Soft maple	13	0	5	4	22	12	0	74	8	14	14	28	67
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	1	0	0	1	0	5	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	5	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	21	0	15	13	15	23	0	22	23	160	0	26	320
Quaking aspen	14	19	9	5	13	9	0	65	0	71	21	20	135
Basswood	1	0	0	2	0	5	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	3	0	0	0	0	0	0	0
Black cherry	4	0	4	5	0	8	0	19	0	0	0	12	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	7	0	5	1	5	0	0	0	0	91	0	42	144
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	108	19	57	61	118	123	62	220	66	479	126	252	666
All species	941	126	265	850	1,086	1,240	827	1,425	1,289	1,590	1,850	1,809	1,271
Number of plots	226	12	32	68	41	26	7	9	9	7	4	10	1
Standard error[3/]	49	49	49	75	120	102	108	199	141	354	665	232	R
Average basal area	97	35	49	112	119	101	57	112	90	119	123	117	86

1/ Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

3/ R indicates that there was an insufficient number of plots to compute the standard error.

Table 3.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

White pine forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:												
White pine	713	59	278	141	399	343	450	810	839	1,029	843	1,007	1,234
Red pine	91	41	86	34	0	178	109	84	104	76	140	43	61
Jack pine	19	0	0	0	0	18	32	0	58	5	30	40	0
White spruce	44	25	43	29	0	17	66	98	10	17	27	82	92
Black spruce	19	0	0	0	60	9	19	6	17	62	17	13	20
Balsam fir	27	13	13	18	0	31	32	48	5	57	9	13	45
Hemlock	13	0	0	0	0	4	25	17	27	0	27	29	0
Tamarack	3	0	0	0	0	0	0	0	0	0	28	0	0
Northern white-cedar	14	0	36	0	0	0	14	28	28	29	0	13	0
Other softwoods	8	0	0	6	0	82	0	0	0	0	0	0	0
Total	950	137	457	228	460	680	748	1,091	1,088	1,275	1,122	1,240	1,452
Hardwoods:												
Select white oaks	18	0	48	0	0	0	8	12	0	0	112	0	0
Select red oaks	25	0	0	23	0	81	0	44	10	14	58	24	8
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	0	0	0	0	0	7	14
Hard maple	18	0	0	0	0	0	0	0	0	46	37	50	44
Soft maple	50	19	0	35	0	37	68	27	22	77	35	69	138
Beech	2	0	0	0	0	0	0	0	5	0	0	0	14
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	2	0	0	8	0	0	9	9	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	14	0	0	0	0	53	32	0	37	0	14	0	0
Quaking aspen	73	10	11	141	119	67	49	36	83	96	60	59	127
Basswood	1	0	0	0	61	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	4	0	0	0	0	26	6	0	0	6	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	0	0	0	6	0	5	0	0	0
Paper birch	51	0	13	0	0	78	33	124	31	95	34	45	55
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	261	29	72	207	180	341	204	258	188	338	351	254	400
All species	1,211	166	529	435	640	1,021	952	1,348	1,275	1,613	1,472	1,494	1,852
Number of plots	102	4	6	7	2	9	9	10	13	12	12	8	10
Standard error[3/]	73	58	106	183	278	204	208	250	191	109	223	281	180
Average basal area	86	32	40	72	62	93	79	88	89	99	100	97	105

[1/] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3/] R indicates that there was an insufficient number of plots to compute the standard error.

Table 4.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Exotics forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	10	0	0	0	0	0	176	0	0	0	0	0	0
Red pine	48	0	0	38	284	0	86	0	0	0	0	0	0
Jack pine	8	6	0	0	0	0	133	0	0	0	0	0	0
White spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	1	0	0	0	0	49	0	0	0	0	0	0	0
Other softwoods	275	28	129	376	496	516	722	0	0	0	0	0	0
Total	342	34	129	414	780	565	1,117	0	0	0	0	0	0
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	5	0	0	15	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	6	0	0	0	0	0	0	0	0	0	0
Hard maple	9	0	13	0	40	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	5	0	0	14	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	12	0	4	0	30	264	0	0	0	0	0	0	0
Basswood	2	0	0	0	20	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	8	0	6	0	57	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	1	0	0	0	0	51	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	43	0	28	29	148	315	0	0	0	0	0	0	0
All species	385	34	157	443	929	880	1,117	0	0	0	0	0	0
Number of plots	37	6	12	12	4	1	2	0	0	0	0	0	0
Standard error[3/]	69	17	42	99	164	R	521	0	0	0	0	0	0
Average basal area	76	31	58	101	109	101	92	0	0	0	0	0	0

1/ Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

3/ R indicates that there was an insufficient number of plots to compute the standard error.

Table 5.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Black spruce forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	30	17	18	19	12	41	28	18	93	0	145	60	140
Red pine	12	5	22	0	0	23	26	11	0	0	0	30	0
Jack pine	18	27	19	26	3	7	20	25	0	0	0	60	0
White spruce	10	0	1	3	4	32	1	23	0	0	0	105	13
Black spruce	266	147	139	155	245	332	428	410	547	934	402	282	205
Balsam fir	39	19	7	24	27	54	50	80	24	0	108	106	165
Hemlock	4	0	9	6	0	1	2	0	0	0	0	15	44
Tamarack	25	21	16	17	30	50	33	45	5	0	0	0	0
Northern white-cedar	48	4	20	15	9	34	26	42	149	0	238	363	477
Other softwoods	0	0	0	0	0	0	1	0	0	0	0	0	0
Total	453	239	251	265	329	576	615	654	818	934	893	1,020	1,044
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	0	0	2	2	0	0	0	25	35
Hard maple	0	0	0	0	2	0	0	0	0	0	13	0	0
Soft maple	10	2	3	5	16	7	8	19	39	0	0	47	29
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	2	0	0	0	0	0	0	5	0	0	0	0	73
Balsam poplar	3	2	0	0	0	13	2	5	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	3	18	0	0	7	2	0	0	0	0	0	0	0
Quaking aspen	27	19	12	11	49	49	28	32	8	0	0	150	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	1	0	0	0	0	2	3	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	27	13	6	11	23	67	33	42	77	0	90	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	74	54	22	26	98	140	76	107	124	0	103	223	136
All species	527	294	273	291	427	717	691	760	942	934	995	1,242	1,180
Number of plots	244	32	44	39	21	29	32	20	9	2	4	6	6
Standard error	28	56	33	34	94	66	59	106	226	295	178	180	254
Average basal area	70	37	47	60	78	82	82	91	117	101	100	122	123

[1/] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 6.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Balsam fir forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	41	12	5	13	16	43	42	23	58	82	127	151	207
Red pine	7	2	2	0	2	2	8	15	0	0	121	0	0
Jack pine	1	0	0	0	7	0	0	3	0	0	0	10	0
White spruce	93	59	17	14	104	130	85	123	148	175	181	121	105
Black spruce	45	40	28	55	34	59	51	67	51	51	22	7	11
Balsam fir	340	97	93	126	388	487	425	450	548	521	417	251	386
Hemlock	14	0	8	13	16	10	9	23	5	34	34	60	0
Tamarack	9	9	32	4	10	12	0	0	6	7	0	7	0
Northern white-cedar	92	41	28	89	95	68	71	113	95	164	315	272	159
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	641	261	213	314	673	812	691	817	912	1,032	1,218	879	867
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	1	0	0	0	0	0	6	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	18	0	0	4	18	34	12	7	23	44	36	69	46
Hard maple	9	0	5	2	2	21	3	24	3	11	20	35	0
Soft maple	61	28	21	5	34	91	75	98	37	101	133	115	118
Beech	0	0	0	0	5	0	0	0	0	0	0	0	0
Ash	7	4	1	1	13	2	3	8	0	40	7	26	19
Balsam poplar	19	8	2	4	17	28	21	9	55	58	57	5	8
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	3	0	3	0	0	0	2	2	33	6	0	0	8
Quaking aspen	76	25	41	34	106	124	104	71	110	53	65	27	63
Basswood	0	0	0	0	2	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	6	0	0	2	0	8	2	21	3	42	0	6	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	8	0	2	1	25	10	6	2	30	4	0	5	0
Paper birch	73	48	71	17	35	58	121	120	81	59	126	84	77
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	282	113	147	71	256	376	354	362	376	419	445	372	340
All species	924	374	360	385	929	1,187	1,045	1,179	1,288	1,451	1,664	1,251	1,207
Number of plots	336	34	39	29	33	53	52	32	21	13	9	12	9
Standard error	31	43	37	50	65	66	53	72	121	126	286	140	218
Average basal area	93	44	52	84	101	111	98	115	110	120	126	112	98

[1/]Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 7.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Northern white-cedar forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	28	0	8	3	16	40	15	14	8	25	50	43	77
Red pine	2	0	0	0	0	4	6	1	1	3	2	0	1
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	29	10	4	1	4	3	43	20	26	30	35	51	62
Black spruce	55	36	30	39	23	51	97	41	51	69	62	59	61
Balsam fir	84	14	22	26	47	83	151	87	112	94	119	88	68
Hemlock	10	0	3	0	3	0	7	8	7	1	31	11	37
Tamarack	21	28	19	41	6	18	12	44	21	10	25	20	6
Northern white-cedar	691	171	190	249	354	431	634	793	805	745	999	900	1,023
Other softwoods	1	0	13	0	0	0	1	0	0	0	0	0	0
Total	920	259	290	359	453	631	966	1,008	1,030	977	1,322	1,172	1,335
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	11	0	0	1	3	0	11	16	8	12	16	15	30
Hard maple	4	0	0	0	0	0	7	0	0	2	0	4	29
Soft maple	32	0	6	8	10	31	21	29	33	57	47	50	40
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	19	0	7	1	8	23	17	27	30	31	21	22	15
Balsam poplar	16	1	3	3	3	42	17	22	25	8	39	8	17
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	3	0	0	0	0	21	2	3	1	1	0	2	6
Quaking aspen	20	18	11	2	19	12	42	21	23	25	13	17	25
Basswood	1	0	0	0	2	0	3	1	1	1	0	2	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	1	0	0	0	1	1	0	1	1
Butternut	0	0	0	0	0	0	0	0	2	0	0	0	0
Elm	2	4	3	0	3	0	3	3	1	2	0	2	0
Paper birch	70	14	12	17	42	91	92	77	88	103	89	72	64
Other hardwoods	0	0	0	0	0	0	0	0	0	1	0	0	1
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	181	36	43	33	89	220	215	201	212	242	226	194	227
All species	1,100	296	333	392	542	851	1,181	1,209	1,242	1,219	1,547	1,365	1,562
Number of plots	651	15	32	51	43	37	59	76	69	71	46	82	70
Standard error	25	71	48	43	48	74	65	60	60	57	98	69	73
Average basal area	132	43	69	94	115	132	142	145	152	141	152	141	147

1/ Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 8.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Tamarack forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	9	14	0	49	0	0	0	0	0	0	0	0	0
Red pine	3	18	0	0	0	0	0	0	0	0	0	0	0
Jack pine	4	0	0	0	0	0	0	38	0	0	0	0	0
White spruce	1	0	0	0	0	11	0	0	0	0	0	0	0
Black spruce	43	0	59	35	8	103	58	64	75	0	44	31	0
Balsam fir	18	0	16	7	0	45	30	17	0	0	97	0	49
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	258	163	165	170	104	75	294	385	536	1,075	447	431	664
Northern white-cedar	45	0	41	62	24	0	27	41	40	45	282	140	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	380	194	281	322	136	234	409	545	650	1,120	869	603	712
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	2	0	7	0	0	0	5	0	0	0	0	0	0
Balsam poplar	7	0	17	0	0	0	20	5	0	0	22	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	12	0	8	0	0	74	24	0	0	0	50	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	12	0	31	0	0	53	25	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	33	0	63	0	0	127	73	5	0	0	72	0	0
All species	413	194	344	322	136	360	482	550	650	1,120	942	603	712
Number of plots	64	9	9	9	6	4	11	6	3	1	3	2	1
Standard error[3/]	46	43	98	63	41	141	125	207	328	R	343	131	R
Average basal area	55	24	45	65	51	58	74	63	57	64	75	53	49

[1/]Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3/]R indicates that there was an insufficient number of plots to compute the standard error.

Table 9.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

White spruce forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	62	66	10	0	58	75	76	0	0	0	0	220	0
Red pine	21	0	0	332	0	10	36	0	0	86	0	14	0
Jack pine	9	26	5	0	0	35	0	0	0	0	0	0	0
White spruce	519	84	196	0	542	419	638	1,733	815	844	0	573	661
Black spruce	32	32	0	0	0	76	16	0	29	16	0	99	0
Balsam fir	115	51	48	0	12	79	152	502	67	234	0	154	445
Hemlock	1	0	0	0	0	6	0	0	0	0	0	0	0
Tamarack	5	19	0	136	0	8	0	0	0	0	0	0	0
Northern white-cedar	120	0	0	0	0	11	140	593	126	347	0	252	714
Other softwoods	7	0	0	0	57	0	0	0	0	0	0	0	0
Total	892	277	259	468	669	720	1,058	2,828	1,037	1,527	0	1,313	1,819
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	3	0	0	0	0	0	0	38	20	0	0	0	0
Hard maple	15	0	39	0	0	0	0	58	24	0	0	38	0
Soft maple	34	17	9	0	0	20	19	0	74	154	0	77	0
Beech	1	0	0	0	0	9	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	20	0	0	0	0	18	3	0	31	163	0	22	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	2	0	10	0	0	0	0	0	0	0	0	0	0
Quaking aspen	104	37	12	0	99	169	188	163	162	44	0	119	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	5	0	0	0	43	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	4	0	14	0	0	9	0	0	0	0	0	0	0
Paper birch	37	0	0	0	0	105	39	0	0	18	0	105	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	224	54	84	0	142	330	249	258	312	379	0	361	0
All species	1,116	331	343	468	811	1,049	1,307	3,086	1,349	1,906	0	1,674	1,819
Number of plots	52	4	9	1	6	9	7	2	3	4	0	6	1
Standard error[3/]	106	154	110	R	154	152	160	399	342	349	0	188	R
Average basal area	92	30	42	60	92	87	114	199	116	132	0	120	112

[1/] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

[3/] R indicates that there was an insufficient number of plots to compute the standard error.

Table 10.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1]

Oak-hickory forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	14	6	6	0	10	7	4	15	6	12	32	52	27
Red pine	16	15	19	61	41	28	13	8	3	23	8	9	4
Jack pine	20	6	7	0	35	20	35	30	22	17	14	9	22
White spruce	1	0	0	0	1	0	0	1	0	0	0	0	14
Black spruce	0	0	0	0	0	0	1	0	0	0	4	0	0
Balsam fir	1	0	0	0	0	0	6	0	0	0	0	0	6
Hemlock	0	0	0	0	0	0	0	1	0	0	0	2	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	0	0	0	0	0	0	0	0	0	0	0	2	3
Other softwoods	1	0	0	0	0	0	1	0	4	0	0	0	0
Total	53	27	32	61	87	55	60	54	35	51	58	73	76
Hardwoods:													
Select white oaks	202	38	98	158	111	182	139	195	307	293	293	392	305
Select red oaks	432	163	109	185	370	420	553	518	410	516	531	585	591
Other red oaks	107	21	44	153	64	158	111	131	121	157	91	122	113
Hickory	24	3	12	0	24	26	5	11	71	41	10	41	45
Yellow birch	0	0	0	0	0	0	0	0	0	1	2	1	4
Hard maple	9	0	0	0	12	8	2	6	7	6	45	19	24
Soft maple	63	32	16	18	49	65	95	69	51	81	60	87	47
Beech	2	0	4	0	0	1	2	2	2	3	4	1	0
Ash	13	1	3	16	13	23	5	10	26	11	4	18	55
Balsam poplar	0	1	0	0	1	0	0	0	0	0	0	0	0
Cottonwood	2	0	0	0	12	0	0	3	1	1	0	9	0
Bigtooth aspen	57	12	8	32	57	84	90	97	78	30	35	45	3
Quaking aspen	12	8	7	0	32	14	9	22	4	8	19	10	7
Basswood	4	0	3	0	0	8	0	6	11	3	14	3	6
Yellow-poplar	1	0	0	0	0	0	0	0	5	0	0	6	0
Black walnut	7	0	0	0	21	20	0	29	3	0	0	0	6
Black cherry	19	4	1	9	40	10	11	14	61	24	5	37	7
Butternut	1	0	0	0	5	0	0	0	3	0	0	0	0
Elm	2	0	2	5	5	0	0	4	6	1	0	1	2
Paper birch	8	0	0	0	6	5	8	10	9	19	28	10	0
Other hardwoods	4	0	1	0	5	0	3	2	6	7	15	4	7
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	969	284	307	576	827	1,025	1,034	1,130	1,182	1,204	1,158	1,389	1,220
All species	1,022	311	339	637	914	1,080	1,093	1,184	1,217	1,255	1,216	1,463	1,295
Number of plots	616	62	48	8	35	68	100	72	58	52	36	58	19
Standard error	25	35	32	102	64	63	52	66	87	54	98	93	125
Average basal area	77	30	39	69	73	85	87	89	84	84	88	95	90

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 11.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1]

Elm-ash-soft maple forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	15	8	4	4	3	6	1	5	0	15	8	96	47
Red pine	2	2	0	1	0	0	5	4	8	0	0	0	0
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	14	2	3	2	5	0	20	15	13	22	14	50	33
Black spruce	7	5	2	10	12	9	8	4	11	6	7	7	3
Balsam fir	40	7	19	16	33	46	54	75	25	24	71	60	92
Hemlock	19	1	6	3	9	9	17	2	22	15	80	68	53
Tamarack	5	1	3	6	7	13	13	1	2	0	0	0	10
Northern white-cedar	64	18	25	24	18	55	69	73	110	62	128	100	195
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	165	46	62	67	88	137	187	180	191	143	307	381	433
Hardwoods:													
Select white oaks	13	5	15	2	14	12	14	0	20	47	13	14	2
Select red oaks	7	1	4	1	1	12	7	8	6	27	3	11	0
Other red oaks	1	0	1	0	2	0	3	2	0	0	0	5	0
Hickory	1	1	1	0	0	0	2	0	5	0	3	5	0
Yellow birch	27	3	6	2	14	17	34	23	38	27	39	74	96
Hard maple	15	7	5	0	24	9	9	15	16	26	54	21	36
Soft maple	339	96	68	83	305	282	402	431	468	765	621	631	363
Beech	2	0	0	0	0	6	1	3	2	0	6	2	0
Ash	165	49	64	120	138	145	181	265	218	219	211	204	359
Balsam poplar	11	8	3	8	10	9	11	11	12	20	20	15	16
Cottonwood	15	13	9	23	32	5	27	5	9	0	63	7	7
Bigtooth aspen	4	4	0	7	4	7	10	1	12	4	0	0	0
Quaking aspen	37	24	19	16	77	82	47	26	19	30	46	31	28
Basswood	13	4	0	0	23	1	26	19	35	5	23	25	9
Yellow-poplar	0	0	0	0	0	0	0	0	0	6	0	0	0
Black walnut	1	0	0	0	9	0	0	0	4	0	0	0	0
Black cherry	9	4	1	24	25	18	4	3	11	6	12	2	7
Butternut	0	0	0	0	0	0	0	0	5	0	0	0	0
Elm	33	16	15	49	62	36	40	37	38	49	13	13	51
Paper birch	28	23	15	23	32	50	30	58	14	32	6	8	32
Other hardwoods	16	0	8	30	17	0	45	19	5	34	43	7	5
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	737	257	235	389	789	689	894	924	937	1,296	1,178	1,073	1,011
All species	903	303	297	456	877	827	1,081	1,104	1,128	1,439	1,484	1,454	1,444
Number of plots	563	69	68	40	43	56	63	45	40	37	24	46	32
Standard error	29	32	27	50	89	61	75	103	76	115	106	118	104
Average basal area	80	34	49	61	83	79	91	95	98	100	116	107	118

[1] Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 12.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1]

Maple-birch forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
		Stand-age class (years)											
Softwoods:													
White pine	19	12	4	4	16	11	15	22	16	23	24	22	52
Red pine	3	3	1	5	2	2	1	4	7	4	1	3	1
Jack pine	1	6	7	0	0	0	0	2	0	1	0	0	0
White spruce	13	4	6	14	16	7	11	9	16	15	14	26	17
Black spruce	2	0	1	1	2	2	1	1	3	1	2	3	6
Balsam fir	32	10	14	11	48	35	26	34	39	39	31	42	43
Hemlock	74	9	9	32	18	29	37	54	64	92	151	148	239
Tamarack	0	0	0	0	0	0	0	1	0	0	1	1	0
Northern white-cedar	22	2	3	7	6	10	10	16	24	31	43	44	65
Other softwoods	1	2	0	7	3	2	0	1	1	0	0	0	0
Total	167	48	46	81	112	98	104	143	169	206	267	288	424
Hardwoods:													
Select white oaks	6	6	7	16	7	2	7	7	7	9	10	5	2
Select red oaks	28	10	31	16	14	15	35	60	23	36	24	28	27
Other red oaks	2	3	2	1	2	2	1	1	2	3	0	0	2
Hickory	3	1	5	8	2	3	2	3	3	5	10	3	0
Yellow birch	67	7	15	25	28	53	44	53	84	75	109	118	165
Hard maple	441	78	113	195	306	451	496	481	493	581	554	569	599
Soft maple	198	55	74	92	178	213	221	255	236	231	209	245	207
Beech	46	11	21	30	12	35	33	53	60	65	69	68	78
Ash	42	16	18	35	46	44	50	84	52	51	39	33	19
Balsam poplar	3	1	1	0	3	3	3	3	3	0	5	2	3
Cottonwood	2	7	1	1	6	1	1	2	0	1	0	3	1
Bigtooth aspen	21	8	8	6	32	32	39	22	18	19	15	9	8
Quaking aspen	51	31	27	45	98	70	78	52	43	50	37	34	23
Basswood	83	29	19	60	118	150	112	103	87	97	71	43	22
Yellow-poplar	1	0	1	5	0	0	1	2	0	4	1	0	4
Black walnut	0	0	1	4	0	0	0	0	0	1	2	0	0
Black cherry	27	13	19	31	43	47	23	35	33	29	18	20	9
Butternut	0	0	0	1	1	0	0	0	0	0	0	0	0
Elm	27	9	8	37	32	38	28	28	35	23	33	23	26
Paper birch	25	8	9	19	15	25	41	34	30	27	21	23	23
Other hardwoods	4	4	3	10	16	3	2	3	0	3	1	5	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,076	300	382	637	959	1,186	1,219	1,282	1,209	1,309	1,230	1,232	1,217
All species	1,243	347	428	719	1,071	1,284	1,322	1,425	1,378	1,516	1,497	1,520	1,641
Number of plots	2,928	220	184	84	156	405	433	231	208	237	226	348	196
Standard error	12	19	20	53	39	25	24	34	40	37	37	31	44
Average basal area	99	39	54	86	93	105	106	107	105	110	112	113	118

1/Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

2/Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 13.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Aspen forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	12	6	7	16	13	7	15	10	19	18	22	96	41
Red pine	13	12	4	13	25	6	17	2	24	25	36	35	0
Jack pine	5	3	8	9	1	8	4	0	5	3	9	0	0
White spruce	20	6	5	16	17	29	30	47	22	24	24	54	0
Black spruce	4	1	2	5	2	6	9	1	1	8	0	5	15
Balsam fir	47	15	11	29	47	80	76	80	75	49	39	80	129
Hemlock	3	2	0	0	4	2	3	9	5	0	15	10	0
Tamarack	2	2	0	1	2	1	4	2	0	0	0	23	0
Northern white-cedar	33	6	6	20	21	30	39	53	86	79	158	173	490
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	138	52	44	110	133	169	197	204	236	206	304	477	676
Hardwoods:													
Select white oaks	4	3	3	2	2	3	8	2	11	2	18	5	0
Select red oaks	30	14	23	20	24	26	26	73	62	57	51	71	0
Other red oaks	2	0	2	4	2	3	1	0	4	0	3	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	2	0	0	0	3	3	4	5	2	2	13	0	0
Hard maple	18	7	7	9	24	24	18	26	52	40	27	12	0
Soft maple	64	27	31	24	79	78	90	123	92	99	72	86	130
Beech	2	1	0	3	3	4	0	4	0	0	2	0	0
Ash	10	4	3	10	17	14	9	9	25	18	13	53	0
Balsam poplar	50	8	12	41	57	74	62	51	74	99	130	335	236
Cottonwood	2	0	0	5	1	1	0	12	0	3	9	0	0
Bigtooth aspen	146	29	44	57	117	185	274	325	334	178	161	153	11
Quaking aspen	312	92	108	203	451	454	468	467	563	488	365	243	290
Basswood	6	2	1	3	3	9	2	5	22	10	40	31	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	6	6	6	14	4	6	4	5	4	4	19	6	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	5	1	5	5	5	8	10	3	4	0	2	17	0
Paper birch	54	14	19	36	51	76	78	105	70	107	83	114	91
Other hardwoods	1	1	0	0	2	0	1	0	2	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	712	211	265	436	845	967	1,055	1,215	1,322	1,106	1,009	1,127	758
All species	850	263	309	546	978	1,136	1,252	1,419	1,558	1,312	1,312	1,603	1,433
Number of plots	1,529	325	252	65	133	239	222	118	64	48	34	25	4
Standard error	17	14	16	52	41	37	36	59	84	93	102	150	464
Average basal area	73	31	46	69	84	93	98	104	108	97	101	114	119

1/ Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 14.--Cubic foot volume per acre in growing-stock trees by species group and stand-age class, Michigan, 1980[1/]

Paper birch forest type - All site index classes

(In cubic feet per acre)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	18	0	3	9	34	30	9	6	35	87	67	41	0
Red pine	10	5	0	0	10	2	4	13	49	0	45	0	0
Jack pine	10	0	0	0	0	0	35	2	0	39	0	0	0
White spruce	29	27	5	0	12	71	16	26	29	77	37	41	75
Black spruce	8	0	0	9	29	4	3	9	20	11	0	0	29
Balsam fir	62	26	35	30	118	73	48	62	54	69	98	126	223
Hemlock	10	0	11	0	9	5	21	0	18	0	0	114	0
Tamarack	3	6	0	0	0	0	6	0	0	0	0	0	41
Northern white-cedar	80	10	21	23	68	34	100	71	210	102	222	92	84
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	230	73	75	71	280	219	242	189	414	385	468	414	451
Hardwoods:													
Select white oaks	2	0	0	0	6	0	5	2	0	0	0	0	0
Select red oaks	17	0	0	0	5	17	33	6	30	99	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	2	0	0	0	0	0	0
Yellow birch	7	0	0	0	15	3	7	6	5	10	9	147	0
Hard maple	39	10	3	0	11	52	42	49	74	52	12	0	183
Soft maple	109	19	29	22	116	146	158	83	133	118	152	318	112
Beech	2	0	0	0	0	4	5	0	0	0	0	0	0
Ash	15	0	3	0	34	14	26	18	16	0	0	0	0
Balsam poplar	14	2	2	0	12	13	24	21	3	13	0	0	28
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	26	9	0	14	18	29	14	42	64	73	35	0	0
Quaking aspen	87	18	15	96	125	123	98	75	118	36	165	78	132
Basswood	13	0	0	0	26	47	20	2	4	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	2	0	5	0	6	3	0	0	0	8	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	3	0	3	10	5	8	0	3	0	12	0	0	0
Paper birch	535	161	160	190	407	519	736	647	594	663	619	735	701
Other hardwoods	0	0	0	0	0	0	0	2	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	869	219	221	332	785	976	1,170	957	1,041	1,084	993	1,279	1,156
All species	1,099	292	296	403	1,065	1,195	1,411	1,145	1,455	1,469	1,462	1,692	1,607
Number of plots	190	15	18	6	13	23	45	36	15	6	7	2	4
Standard error	47	73	58	87	132	92	87	95	176	124	157	215	132
Average basal area	94	38	47	75	89	103	113	98	108	124	112	116	117

[1/]Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average volume per acre for all ages in the forest type and index range.

Table 15.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Jack pine forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	760	560	920	0	620	1,100	460	0	840	4,160	8,280	0	0
Red pine	2,620	1,100	1,980	1,580	4,120	3,140	2,060	1,380	4,040	4,900	5,740	0	0
Jack pine	29,840	10,500	15,620	24,760	29,180	40,200	34,340	41,040	37,840	31,140	25,500	24,380	19,700
White spruce	20	0	0	0	0	40	60	0	0	0	0	0	0
Black spruce	640	300	80	0	500	1,880	540	0	200	0	1,160	0	0
Balsam fir	40	0	0	0	60	80	20	0	140	0	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	60	0	0	0	0	0	0	0	0
Northern white-cedar	20	0	0	0	80	0	0	0	0	0	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	33,940	12,460	18,600	26,340	34,620	46,440	37,480	42,420	43,060	40,200	40,680	24,380	19,700
Hardwoods:													
Select white oaks	160	260	0	140	80	80	480	420	0	0	0	0	0
Select red oaks	2,300	3,600	1,100	140	1,520	3,720	2,260	1,040	2,800	820	12,120	19,180	0
Other red oaks	1,000	140	120	540	1,420	1,000	1,480	2,300	1,600	0	0	0	0
Hickory	20	0	0	0	0	80	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	60	0	0	0	0	280	20	0	0	0	0	0	0
Soft maple	680	900	500	80	700	500	520	20	3,020	0	5,320	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	240	440	200	1,120	0	280	140	0	0	0	0	0	0
Quaking aspen	720	80	640	180	800	940	1,220	760	680	780	0	0	0
Basswood	0	0	0	0	0	40	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	80	80	60	0	120	40	140	0	40	780	0	0	0
Butternut	20	0	0	0	0	80	0	0	0	0	0	0	0
Elm	20	0	0	0	0	100	0	0	0	0	0	0	0
Paper birch	120	360	100	0	200	20	0	0	340	0	2,520	0	0
Other hardwoods	0	0	0	0	0	40	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	40	0	0	0	0	0	0	0
Total	5,420	5,860	2,720	2,200	4,840	7,240	6,260	4,540	8,480	2,380	19,960	19,180	0
All species	39,360	18,320	21,320	28,540	39,460	53,680	43,740	46,960	51,540	42,580	60,640	43,560	19,700
Number of plots	346	35	40	31	56	76	52	24	21	7	2	1	1
Standard error[3/]	1,500	3,140	2,860	4,660	3,460	3,340	3,760	5,580	5,340	9,320	4,320	R	R
Average basal area	65	27	45	59	65	86	75	71	68	70	74	56	30

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

3/ R indicates that there was an insufficient number of plots to compute the standard error.

Table 16.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Red pine forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	2,320	300	500	240	360	1,980	940	11,100	5,280	9,280	11,720	14,600	10,540
Red pine	41,040	17,300	23,660	46,520	44,040	45,820	29,660	42,940	50,500	42,660	69,500	49,440	27,840
Jack pine	4,520	1,280	1,200	3,400	5,880	11,800	5,580	300	10,200	1,980	0	4,360	0
White spruce	240	200	0	60	200	0	0	120	1,020	0	2,800	1,740	0
Black spruce	200	0	0	0	100	320	0	280	400	260	3,540	1,140	0
Balsam fir	440	640	0	540	60	260	0	1,920	260	740	620	1,780	0
Hemlock	120	0	0	0	0	0	0	3,020	0	0	0	0	0
Tamarack	40	0	0	0	180	0	0	0	0	0	0	0	0
Northern white-cedar	140	0	0	60	180	60	0	1,060	0	0	1,040	520	0
Other softwoods	320	0	600	240	380	0	0	2,400	0	0	0	0	0
Total	49,380	19,720	25,960	51,060	51,380	60,240	36,180	63,140	67,660	54,920	89,220	73,580	38,380
Hardwoods:													
Select white oaks	740	0	660	740	1,520	780	1,400	0	500	0	0	0	0
Select red oaks	1,680	0	1,000	400	1,000	2,800	3,200	3,040	1,600	9,540	6,760	4,940	0
Other red oaks	840	0	20	940	1,760	740	0	0	0	0	0	3,300	0
Hickory	60	0	0	80	0	340	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	300	0	680	600	0	0	0	580	0	0	0	0	0
Soft maple	1,420	0	1,140	600	1,380	680	0	9,860	2,220	2,560	4,020	2,360	3,460
Beech	20	0	0	0	0	0	0	0	0	0	0	400	0
Ash	100	0	0	160	140	260	0	0	0	0	0	0	0
Balsam poplar	20	0	0	0	0	0	0	0	0	0	0	260	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	1,500	780	860	920	1,300	1,260	0	1,440	1,080	12,320	2,480	1,180	20,880
Quaking aspen	1,320	1,660	840	480	1,600	1,300	0	3,920	420	3,860	1,520	3,960	6,240
Basswood	60	0	0	120	0	220	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	20	0	0	0	0	180	0	0	0	0	0	0	0
Black cherry	480	0	1,060	460	20	1,020	0	900	0	0	0	600	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	580	0	500	100	360	0	0	360	0	5,960	0	3,920	7,700
Other hardwoods	60	0	40	100	0	140	0	0	0	0	0	0	0
Noncommercial species	20	0	40	0	0	20	0	320	0	0	0	0	0
Total	9,220	2,440	6,840	5,700	9,080	9,740	4,600	20,420	5,820	34,240	14,780	20,920	38,280
All species	58,600	22,160	32,800	56,760	60,460	69,980	40,780	83,560	73,480	89,160	104,000	94,500	76,660
Number of plots	226	12	32	68	41	26	7	9	9	7	4	10	1
Standard error[3/]	2,520	7,240	4,480	4,160	6,420	5,720	5,220	11,180	7,760	18,040	30,300	10,460	R
Average basal area	97	35	49	112	119	101	57	112	90	119	123	117	86

[1/]Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

[3/]R indicates that there was an insufficient number of plots to compute the standard error.

Table 17.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

White pine forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	32,220	9,660	13,200	8,880	19,300	19,480	21,660	36,960	39,340	42,400	35,940	45,460	51,380
Red pine	4,700	1,940	4,700	3,580	0	9,500	5,120	3,820	5,480	4,300	6,800	1,900	2,820
Jack pine	1,220	0	0	0	0	1,500	2,740	0	3,020	300	1,840	2,640	0
White spruce	1,900	940	2,640	2,240	0	720	2,600	3,660	360	1,400	1,020	3,060	3,460
Black spruce	1,300	0	0	0	2,920	300	2,740	200	1,700	3,520	1,680	520	820
Balsam fir	2,720	680	620	1,820	0	1,440	2,480	5,640	260	7,580	2,660	1,160	3,100
Hemlock	780	0	0	0	0	200	1,380	820	1,860	20	1,460	1,800	60
Tamarack	200	0	0	0	0	0	200	0	0	0	1,420	100	0
Northern white-cedar	740	0	1,200	0	0	0	460	3,700	860	960	0	640	0
Other softwoods	420	0	0	1,280	0	3,880	0	0	0	0	0	0	0
Total	46,200	13,220	22,360	17,800	22,220	37,020	39,380	54,800	52,880	60,480	52,820	57,280	61,640
Hardwoods:													
Select white oaks	1,260	0	3,380	0	0	0	560	760	0	0	8,000	0	0
Select red oaks	1,900	0	0	1,440	0	5,920	420	3,540	640	1,040	3,740	2,520	500
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	200	0	0	0	0	0	0	0	0	700	0	400	800
Hard maple	1,900	0	0	0	0	0	0	0	0	4,940	4,680	6,100	2,880
Soft maple	4,780	13,100	1,940	5,380	0	3,080	4,700	1,620	1,700	6,340	4,580	4,900	10,800
Beech	400	1,860	0	0	0	0	0	0	620	0	0	0	2,580
Ash	140	0	0	0	0	0	0	0	340	740	0	0	60
Balsam poplar	120	0	0	640	0	0	420	400	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	920	0	0	0	0	4,220	1,740	0	2,280	0	920	0	0
Quaking aspen	5,220	3,660	1,520	7,940	7,220	4,380	3,940	2,880	6,860	5,960	5,600	4,040	7,480
Basswood	60	0	0	0	2,580	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	320	0	0	0	0	2,560	380	0	0	500	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	80	0	0	0	0	0	280	320	0	260	0	0	0
Paper birch	3,160	0	680	520	0	4,520	2,700	7,220	2,560	5,380	2,660	2,420	2,900
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	20	0	0	0	0	0	0	0	0	100	0	0	0
Total	20,480	18,620	7,520	15,920	9,800	24,680	15,140	16,740	15,000	25,960	30,180	20,380	28,000
All species	66,680	31,840	29,880	33,720	32,020	61,700	54,520	71,540	67,880	86,440	83,000	77,660	89,640
Number of plots	102	4	6	7	2	9	9	10	13	12	12	8	10
Standard error	3,540	10,920	5,900	11,580	10,460	8,040	9,280	13,780	7,340	6,800	12,580	13,960	8,900
Average basal area	86	32	40	72	62	93	79	88	89	99	100	97	105

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Table 18.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Exotics forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	360	0	0	0	0	0	6,740	0	0	0	0	0	0
Red pine	3,300	0	600	2,960	16,900	0	6,100	0	0	0	0	0	0
Jack pine	1,000	3,800	0	0	0	0	7,080	0	0	0	0	0	0
White spruce	500	0	0	1,520	0	0	0	0	0	0	0	0	0
Black spruce	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam fir	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	40	0	0	0	0	1,560	0	0	0	0	0	0	0
Other softwoods	30,220	7,380	26,540	40,700	37,180	51,100	33,520	0	0	0	0	0	0
Total	35,420	11,180	27,140	45,180	54,080	52,660	53,440	0	0	0	0	0	0
Hardwoods:													
Select white oaks	100	0	0	0	980	0	0	0	0	0	0	0	0
Select red oaks	720	0	0	1,900	0	0	1,960	0	0	0	0	0	0
Other red oaks	280	1,720	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	120	0	360	0	0	0	0	0	0	0	0	0	0
Hard maple	1,560	0	3,420	0	4,160	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	780	0	0	2,400	0	0	0	0	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	860	0	0	0	0	0	16,020	0	0	0	0	0	0
Quaking aspen	1,720	0	3,540	0	1,420	15,240	0	0	0	0	0	0	0
Basswood	100	0	0	0	860	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	840	0	280	1,300	2,960	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	80	0	0	0	0	3,140	0	0	0	0	0	0	0
Paper birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	120	0	0	0	1,080	0	0	0	0	0	0	0	0
Total	7,280	1,720	7,600	5,600	11,460	18,380	17,980	0	0	0	0	0	0
All species	42,700	12,900	34,740	50,780	65,540	71,040	71,420	0	0	0	0	0	0
Number of plots	37	6	12	12	4	1	2	0	0	0	0	0	0
Standard error[3/]	5,180	4,240	7,680	10,640	8,580	R	10,360	0	0	0	0	0	0
Average basal area	76	31	58	101	109	101	92	0	0	0	0	0	0

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

[3/] R indicates that there was an insufficient number of plots to compute the standard error.

Table 19.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Black spruce forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1,380	680	1,000	980	900	1,760	1,220	860	3,760	0	5,940	2,420	5,980
Red pine	720	220	1,680	160	0	1,080	1,180	480	0	0	0	1,380	0
Jack pine	1,260	1,420	1,360	2,340	160	380	1,380	1,820	0	0	0	3,140	0
White spruce	440	0	40	220	160	1,220	40	860	0	0	0	6,180	480
Black spruce	20,380	9,840	13,560	21,220	25,020	22,640	25,340	30,660	29,140	74,720	21,440	13,440	8,300
Balsam fir	3,800	1,360	2,040	3,340	2,340	4,400	4,700	6,800	2,160	0	5,460	8,600	17,920
Hemlock	260	0	560	300	0	80	80	0	0	0	0	820	2,900
Tamarack	2,320	1,880	2,480	2,060	4,340	3,680	2,060	2,240	260	0	900	0	100
Northern white-cedar	3,060	500	1,720	1,260	320	2,660	1,840	3,400	8,920	0	9,360	21,420	24,420
Other softwoods	0	0	0	0	0	0	60	0	0	0	0	0	0
Total	33,620	15,900	24,440	31,880	33,240	37,900	37,900	47,120	44,240	74,720	43,100	57,400	60,100
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	140	0	0	0	0	0	100	140	0	0	0	2,280	2,720
Hard maple	40	0	0	0	140	0	0	180	120	0	880	0	0
Soft maple	1,460	380	220	2,000	1,260	2,420	700	1,160	3,700	0	4,660	2,700	7,480
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	160	0	0	0	0	0	0	760	0	0	0	0	4,280
Balsam poplar	260	140	40	0	0	800	220	1,260	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	140	820	0	0	340	100	0	0	0	0	0	0	0
Quaking aspen	2,260	1,640	1,380	1,620	2,880	3,840	2,160	2,660	740	0	0	12,560	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	40	0	0	80	0	80	160	0	40	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	60	0	0	0	0	260	200	0	0	0	0	0	0
Paper birch	2,120	860	800	1,520	1,500	4,840	1,940	3,240	4,900	0	9,720	340	1,760
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	140	0	0	140	20	20	820	0	0	0	0	200	0
Total	6,820	3,840	2,440	5,360	6,140	12,360	6,300	9,400	9,500	0	15,260	18,080	16,240
All species	40,440	19,740	26,880	37,240	39,380	50,260	44,200	56,520	53,740	74,720	58,360	75,480	76,340
Number of plots	244	32	44	39	21	29	32	20	9	2	4	6	6
Standard error	1,740	3,140	2,480	3,700	5,960	4,760	4,840	5,400	11,800	12,440	3,920	10,280	14,880
Average basal area	70	37	47	60	78	82	82	91	117	101	100	122	123

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Table 20.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Balsam fir forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1,780	660	200	640	740	1,780	1,740	1,040	2,640	3,460	5,120	6,440	8,860
Red pine	300	100	80	0	80	80	380	680	0	0	5,400	0	0
Jack pine	120	0	0	0	800	0	0	140	0	0	0	560	0
White spruce	4,240	2,520	920	1,360	5,660	5,380	4,080	5,200	6,900	7,600	7,060	6,020	3,900
Black spruce	2,700	2,480	2,920	5,480	2,260	2,960	2,680	2,780	2,000	2,460	780	240	840
Balsam fir	27,280	10,000	14,260	28,000	31,040	33,320	30,880	35,660	35,600	32,020	25,440	23,160	28,020
Hemlock	1,000	0	540	1,380	1,320	1,040	460	1,380	680	1,920	1,820	3,900	260
Tamarack	620	440	1,740	1,100	940	920	40	0	300	320	0	340	0
Northern white-cedar	5,660	1,780	3,400	7,480	4,260	4,060	4,540	11,040	4,120	9,120	14,860	11,380	7,680
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	43,700	17,980	24,060	45,440	47,100	49,540	44,800	57,920	52,240	56,900	60,480	52,040	49,560
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	60	0	20	0	0	0	380	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1,880	0	80	1,420	2,020	2,920	1,760	800	2,960	3,300	5,780	5,540	3,040
Hard maple	1,200	0	300	520	860	2,280	1,420	1,600	1,080	1,420	1,920	3,400	720
Soft maple	5,380	2,400	2,220	2,100	3,520	7,820	5,220	7,720	5,640	9,840	10,040	8,700	9,920
Beech	40	0	0	0	260	0	0	0	0	0	0	400	0
Ash	1,060	1,040	140	1,180	1,260	300	360	1,260	1,340	5,460	3,340	2,400	1,000
Balsam poplar	1,300	1,520	240	860	1,560	1,480	1,260	400	3,440	2,960	2,780	360	360
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	260	0	160	0	0	80	200	140	2,140	280	0	0	1,300
Quaking aspen	5,400	2,340	3,140	2,880	6,740	8,540	7,240	5,280	7,100	4,500	3,080	2,020	5,120
Basswood	20	0	0	0	120	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	580	40	140	140	400	1,000	140	1,620	720	2,860	120	300	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	520	0	100	120	1,800	620	420	360	1,660	220	0	320	20
Paper birch	5,220	3,540	5,340	2,100	4,980	4,180	7,520	7,540	5,800	3,280	7,620	6,040	4,540
Other hardwoods	0	20	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	100	40	0	20	80	300	0	80	20	0	820	40	20
Total	23,020	10,940	11,880	11,340	23,600	29,520	25,920	26,800	31,900	34,120	35,500	29,520	26,040
All species	66,720	28,920	35,940	56,780	70,700	79,060	70,720	84,720	84,140	91,020	95,980	81,560	75,600
Number of plots	336	34	39	29	33	53	52	32	21	13	9	12	9
Standard error	1,840	3,180	3,700	5,580	5,040	4,300	3,820	5,080	6,700	6,720	11,900	6,800	10,740
Average basal area	93	44	52	84	101	111	98	115	110	120	126	112	98

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Table 21.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1]

Northern white-cedar forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	1,220	0	320	140	880	1,560	700	620	320	1,120	2,080	1,760	3,500
Red pine	80	0	0	0	0	200	340	40	60	120	80	0	60
Jack pine	0	0	0	0	0	0	0	0	0	0	0	0	0
White spruce	1,320	400	280	60	240	240	2,340	1,040	1,240	1,160	1,980	2,000	2,600
Black spruce	3,300	2,580	2,340	3,000	2,360	4,740	5,220	2,480	2,340	4,260	3,420	3,340	3,080
Balsam fir	9,360	1,820	5,380	6,560	10,420	9,920	12,960	9,760	12,500	8,480	9,760	10,000	7,260
Hemlock	700	0	180	0	420	0	420	720	400	60	2,240	880	2,140
Tamarack	1,940	2,580	2,480	4,380	2,660	2,380	1,440	3,280	1,640	1,300	1,560	1,080	320
Northern white-cedar	43,980	12,180	21,700	31,840	42,880	43,880	43,080	49,480	50,140	45,720	51,400	47,140	48,960
Other softwoods	80	0	1,460	0	0	0	20	0	0	0	0	0	0
Total	61,980	19,560	34,140	45,980	59,860	62,920	66,520	67,420	68,640	62,220	72,520	66,200	67,920
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	1,140	0	0	80	740	320	940	1,580	860	1,240	1,960	1,520	2,320
Hard maple	400	0	0	220	120	0	420	60	140	140	80	400	2,220
Soft maple	2,920	0	1,000	620	1,860	1,880	2,580	2,340	2,880	4,580	4,400	4,800	3,440
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	2,640	120	980	300	2,620	3,500	1,960	3,300	4,220	3,040	2,880	2,800	2,680
Balsam poplar	1,080	320	1,400	840	500	2,620	1,320	1,300	1,460	400	2,080	380	880
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	160	0	0	0	0	1,080	240	160	60	40	0	100	280
Quaking aspen	1,600	820	1,920	900	2,040	1,300	2,580	1,880	1,560	1,880	760	1,060	1,760
Basswood	60	0	0	0	80	0	300	100	40	40	0	120	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	20	0	40	0	60	40	0	0	60	60	0	40	40
Butternut	0	0	0	0	0	0	0	0	80	0	0	0	0
Elm	160	260	140	0	160	0	280	340	280	140	0	220	0
Paper birch	5,420	1,420	2,600	2,460	4,380	8,720	7,980	5,700	6,420	6,800	6,120	4,820	3,960
Other hardwoods	20	0	0	0	0	120	0	0	0	40	0	0	60
Noncommercial species	100	0	20	20	20	40	80	80	40	140	60	80	320
Total	15,720	2,940	8,100	5,440	12,580	19,620	18,680	16,840	18,100	18,540	18,340	16,340	17,960
All species	77,700	22,500	42,240	51,420	72,440	82,540	85,200	84,260	86,740	80,760	90,860	82,540	85,880
Number of plots	651	15	32	51	43	37	59	76	69	71	46	82	70
Standard error	1,380	5,020	5,520	3,760	4,500	5,480	4,420	3,700	3,920	3,640	5,180	3,820	3,640
Average basal area	132	43	69	94	115	132	142	145	152	141	152	141	147

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Tamarack forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	520	740	0	2,940	0	0	0	0	0	0	0	0	0
Red pine	120	800	0	0	0	0	0	0	0	0	0	0	0
Jack pine	180	0	0	0	0	0	0	1,980	0	0	0	0	0
White spruce	40	0	0	0	140	420	0	0	0	0	0	0	0
Black spruce	3,280	0	3,880	4,680	1,500	6,840	5,100	3,080	4,880	0	1,900	1,080	0
Balsam fir	2,100	80	4,620	720	0	2,400	4,420	780	0	0	5,220	2,580	2,280
Hemlock	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarack	22,240	15,580	13,360	33,060	20,800	13,140	23,380	21,200	31,860	52,960	23,120	26,560	33,040
Northern white-cedar	3,280	560	2,420	5,040	5,160	0	3,960	1,300	1,980	1,380	12,140	5,580	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	31,760	17,760	24,280	46,440	27,600	22,800	36,860	28,340	38,720	54,340	42,380	35,800	35,320
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	480	0	1,000	1,220	480	0	0	0	0	0	80	3,780	0
Beech	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	180	0	360	0	0	0	520	0	0	0	620	0	0
Balsam poplar	440	0	1,020	0	0	0	1,180	260	0	0	1,080	840	0
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	760	0	360	0	0	6,400	1,160	0	0	0	2,360	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	0	0	0	0	0	0	0	0	0	0	0	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Paper birch	960	0	3,200	0	0	2,800	1,680	580	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2,820	0	5,940	1,220	480	9,200	4,540	840	0	0	4,140	4,620	0
All species	34,580	17,760	30,220	47,660	28,080	32,000	41,400	29,180	38,720	54,340	46,520	40,420	35,320
Number of plots	64	9	9	9	6	4	11	6	3	1	3	2	1
Standard error[3]	2,900	2,780	9,500	6,400	7,660	7,560	8,360	11,120	19,880	R	15,340	9,400	R
Average basal area	55	24	45	65	51	58	74	63	57	64	75	53	49

1/Forest type definitions and species list are in the appendix.

2/Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

3/R indicates that there was an insufficient number of plots to compute the standard error.

Table 23.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

White spruce forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	3,120	2,620	540	0	3,480	3,320	4,540	0	0	780	0	10,220	0
Red pine	1,000	0	0	17,620	0	440	1,620	0	0	3,780	0	700	0
Jack pine	540	1,340	260	0	0	2,260	0	0	0	0	0	0	0
White spruce	25,160	3,280	16,620	8,980	32,080	19,140	32,840	71,460	36,800	31,780	0	22,660	25,460
Black spruce	1,500	1,340	0	0	0	2,680	2,540	0	2,600	620	0	3,420	0
Balsam fir	8,360	4,040	2,960	0	600	4,740	11,860	28,580	9,460	16,440	0	12,340	37,220
Hemlock	60	0	0	0	0	340	0	0	0	0	0	0	0
Tamarack	280	960	0	6,680	0	400	0	0	0	0	0	0	0
Northern white-cedar	6,480	0	0	0	0	360	11,740	33,100	4,600	19,840	0	11,040	26,640
Other softwoods	860	0	2,100	0	4,220	0	0	0	0	0	0	0	0
Total	47,360	13,580	22,480	33,280	40,380	33,680	65,140	133,140	53,460	73,240	0	60,380	89,320
Hardwoods:													
Select white oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	260	0	0	0	0	0	0	5,240	1,160	0	0	0	0
Hard maple	1,320	0	2,280	0	0	0	0	8,620	1,420	0	0	4,400	0
Soft maple	3,240	1,120	440	0	0	3,420	2,960	0	13,940	10,000	0	4,400	0
Beech	320	0	0	0	0	1,860	0	0	0	0	0	0	0
Ash	100	0	0	0	0	0	0	2,400	0	0	0	0	0
Balsam poplar	1,380	0	0	0	0	1,820	160	0	3,620	7,020	0	2,060	2,760
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	80	0	460	0	0	0	0	0	0	0	0	0	0
Quaking aspen	8,980	2,620	4,240	0	8,240	12,380	11,960	8,020	15,560	4,760	0	15,340	0
Basswood	60	0	0	0	0	340	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	360	0	0	0	2,440	0	0	0	620	0	0	300	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	220	0	800	0	0	500	0	0	0	0	0	0	0
Paper birch	2,440	0	0	0	0	5,960	3,000	0	0	3,620	0	6,300	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	20	0	0	0	0	0	120	0	0	0	0	0	0
Total	18,780	3,740	8,220	0	10,680	26,280	18,200	24,280	36,320	25,400	0	32,800	2,760
All species	66,140	17,320	30,700	33,280	51,060	59,960	83,340	157,420	89,780	98,640	0	93,180	92,080
Number of plots	52	4	9	1	6	9	7	2	3	4	0	6	1
Standard error[3/]	5,660	5,100	8,380	R	11,080	9,320	10,400	22,360	22,520	19,280	0	10,880	R
Average basal area	92	30	42	60	92	87	114	199	116	132	0	120	112

[1/]Forest type definitions and species list are in the appendix.

[2/]Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

[3/]R indicates that there was an insufficient number of plots to compute the standard error.

Oak-hickory forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	820	560	380	0	580	420	460	940	680	760	1,640	2,140	1,160
Red pine	980	780	1,060	8,140	2,460	1,360	760	580	140	1,740	400	420	200
Jack pine	1,460	580	1,660	1,000	2,820	1,160	2,000	1,820	1,340	1,520	1,000	620	1,860
White spruce	40	0	0	0	420	0	0	20	0	0	0	40	520
Black spruce	20	0	0	0	0	0	20	0	0	0	280	0	0
Balsam fir	120	0	0	0	0	20	440	0	0	0	20	220	800
Hemlock	20	0	0	0	0	0	0	40	0	0	0	120	0
Tamarack	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern white-cedar	20	0	0	0	0	0	0	0	0	0	0	60	200
Other softwoods	40	0	80	0	0	0	60	0	200	0	0	0	0
Total	3,520	1,920	3,180	9,140	6,280	2,960	3,740	3,400	2,360	4,020	3,340	3,620	4,740
Hardwoods:													
Select white oaks	15,580	3,980	8,800	12,680	9,580	14,480	10,920	14,580	22,960	21,540	23,220	28,260	23,060
Select red oaks	30,480	12,440	8,520	16,720	27,300	29,800	39,180	36,180	28,340	35,520	38,820	39,280	41,560
Other red oaks	7,780	1,420	4,380	10,020	5,180	11,280	8,380	9,220	8,200	11,440	6,180	9,260	7,140
Hickory	1,900	440	1,260	0	2,440	2,080	500	720	5,300	3,280	720	3,300	3,120
Yellow birch	60	0	0	0	0	0	0	0	0	180	80	240	400
Hard maple	780	20	0	0	920	700	320	620	620	340	3,000	1,840	2,700
Soft maple	5,340	2,980	2,080	2,500	3,140	5,840	7,620	6,080	4,920	5,700	4,900	6,640	7,240
Beech	160	20	220	0	0	60	300	140	120	220	640	60	0
Ash	840	80	380	800	880	1,280	320	720	1,620	740	380	1,140	4,000
Balsam poplar	0	60	0	0	60	0	0	0	0	0	0	0	0
Cottonwood	140	0	0	0	620	0	40	200	80	120	0	640	0
Bigtooth aspen	3,320	880	940	4,140	2,880	4,480	5,200	5,340	4,480	2,060	1,860	2,780	380
Quaking aspen	1,020	780	1,260	0	2,440	880	860	1,660	740	720	1,100	680	520
Basswood	260	0	160	0	80	400	60	260	800	200	740	160	600
Yellow-poplar	40	0	0	0	0	0	0	0	240	0	0	280	0
Black walnut	480	0	0	0	1,440	1,460	0	1,840	180	0	0	0	360
Black cherry	1,320	540	780	440	2,240	760	800	880	3,440	1,720	660	2,200	1,100
Butternut	60	0	0	0	620	0	0	0	220	0	0	0	0
Elm	260	0	280	300	640	80	20	440	580	120	0	220	1,480
Paper birch	580	0	200	0	440	280	560	560	520	1,020	1,980	920	140
Other hardwoods	600	260	180	920	420	60	260	680	860	1,160	1,740	780	1,160
Noncommercial species	420	660	420	480	860	240	180	180	980	200	340	120	1,740
Total	71,420	24,560	29,860	49,000	62,180	74,160	75,520	80,300	85,200	86,280	86,360	98,800	96,700
All species	74,940	26,480	33,040	58,140	68,460	77,120	79,260	83,700	87,560	90,300	89,700	102,420	101,440
Number of plots	616	62	48	8	35	68	100	72	58	52	36	58	19
Standard error	1,640	2,820	2,620	5,120	4,000	4,040	3,580	4,500	5,380	3,780	6,640	5,660	8,940
Average basal area	77	30	39	69	73	85	87	89	84	84	88	95	90

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Table 25.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Elm-ash-soft maple forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	680	320	340	180	120	220	60	180	60	600	400	4,380	2,040
Red pine	80	120	0	60	0	0	240	180	400	0	0	0	0
Jack pine	20	100	0	20	0	0	0	0	0	0	0	0	0
White spruce	600	80	120	60	200	280	820	580	640	1,320	540	1,960	1,240
Black spruce	320	440	60	340	480	300	300	120	500	220	260	520	420
Balsam fir	3,440	480	2,000	2,140	2,540	4,640	4,440	4,760	3,020	1,820	8,400	4,920	6,420
Hemlock	1,260	100	380	180	500	760	1,440	180	1,520	1,040	5,200	4,160	2,960
Tamarack	300	200	140	320	660	680	700	80	100	0	0	0	500
Northern white-cedar	3,580	1,240	1,260	3,020	1,380	3,300	4,040	4,260	6,200	2,620	7,620	5,220	8,460
Other softwoods	0	0	0	40	0	0	0	0	0	0	0	0	0
Total	10,280	3,080	4,300	6,360	5,880	10,180	12,040	10,340	12,440	7,620	22,420	21,160	22,040
Hardwoods:													
Select white oaks	980	280	1,260	120	940	1,020	1,120	0	1,720	3,320	940	1,100	180
Select red oaks	500	100	400	80	200	940	600	500	400	1,740	240	720	0
Other red oaks	100	0	60	0	120	0	460	100	0	0	0	360	0
Hickory	100	60	180	0	0	0	180	0	340	0	200	320	0
Yellow birch	2,640	600	660	720	1,380	1,980	3,240	2,720	3,160	2,300	4,740	5,700	9,080
Hard maple	1,520	480	880	40	1,960	980	1,120	1,580	1,340	3,480	4,500	1,780	3,400
Soft maple	22,920	7,240	9,140	6,840	22,880	19,460	24,740	27,140	31,920	46,280	41,660	39,320	26,900
Beech	120	0	60	0	0	340	80	220	140	0	460	260	0
Ash	14,360	5,200	8,460	16,660	14,820	12,740	15,860	21,320	18,720	15,800	16,540	14,100	24,900
Balsam poplar	640	840	400	620	560	620	540	460	580	940	1,100	640	680
Cottonwood	900	940	560	1,360	1,940	540	1,440	260	480	0	3,560	400	340
Bigtooth aspen	260	200	0	460	260	400	560	180	660	280	0	0	0
Quaking aspen	2,500	2,360	2,000	1,340	4,160	5,100	3,140	1,500	1,860	1,700	2,560	1,660	1,440
Basswood	760	200	0	0	1,080	40	1,400	980	1,880	360	1,900	1,780	620
Yellow-poplar	20	0	0	0	0	0	0	0	0	240	0	0	0
Black walnut	60	0	0	0	680	0	0	0	260	0	0	0	0
Black cherry	660	540	80	1,480	1,600	1,180	320	300	640	360	1,060	400	480
Butternut	40	0	0	0	0	0	0	0	300	80	380	0	0
Elm	3,120	1,760	2,880	4,940	6,220	2,840	3,100	3,060	2,860	3,340	1,700	1,600	3,880
Paper birch	2,040	1,540	1,760	2,120	2,100	3,720	2,380	3,160	1,160	2,240	700	880	1,780
Other hardwoods	1,320	320	1,820	2,580	1,280	0	2,860	1,200	280	2,000	3,460	700	260
Noncommercial species	500	380	400	720	540	460	140	740	700	200	1,620	420	420
Total	56,060	23,040	31,000	40,080	62,720	52,360	63,280	65,420	69,400	84,660	87,320	72,140	74,360
All species	66,340	26,120	35,300	46,440	68,600	62,540	75,320	75,760	81,840	92,280	109,740	93,300	96,400
Number of plots	563	69	68	40	43	56	63	45	40	37	24	46	32
Standard error	1,680	2,300	2,680	3,500	5,460	4,300	4,400	5,320	4,760	6,360	6,580	5,960	6,060
Average basal area	80	34	49	61	83	79	91	95	98	100	116	107	118

[1/] Forest type definitions and species list are in the appendix.

[2/] Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Maple-birch forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	840	580	320	380	740	500	740	1,040	740	1,120	1,040	880	2,100
Red pine	160	200	220	380	100	140	80	260	360	240	20	140	60
Jack pine	100	460	580	0	0	20	60	120	0	60	20	0	0
White spruce	580	160	340	620	760	340	480	360	760	640	620	1,120	760
Black spruce	100	40	40	60	120	100	80	100	100	40	160	180	240
Balsam fir	2,420	740	1,660	1,080	3,460	2,560	2,200	2,500	2,720	2,720	2,220	3,000	3,340
Hemlock	4,720	520	780	2,080	1,460	1,960	2,640	4,120	4,340	5,760	9,680	8,760	14,160
Tamarack	20	60	0	0	0	20	20	20	20	0	40	40	0
Northern white-cedar	1,200	180	140	1,000	640	620	540	820	1,400	1,700	2,120	2,380	3,080
Other softwoods	80	280	80	300	340	80	0	40	40	0	40	20	0
Total	10,220	3,220	4,160	5,900	7,620	6,340	6,840	9,380	10,480	12,280	15,960	16,520	23,740
Hardwoods:													
Select white oaks	480	480	480	1,260	540	180	500	520	560	620	860	380	160
Select red oaks	1,960	780	2,420	1,180	1,020	1,080	2,360	4,060	1,640	2,600	1,620	2,040	2,080
Other red oaks	120	200	220	80	140	120	100	40	180	200	0	0	140
Hickory	260	200	340	620	140	240	140	220	240	320	700	200	0
Yellow birch	6,360	1,140	2,400	2,300	2,800	5,140	4,280	5,160	7,800	6,560	10,220	11,060	14,520
Hard maple	34,920	7,260	12,220	23,500	27,920	37,540	39,820	36,260	37,960	43,120	41,620	43,040	44,520
Soft maple	13,920	5,080	7,360	10,120	13,000	14,680	15,240	16,400	15,860	15,540	14,420	16,900	14,900
Beech	3,840	1,140	2,160	2,500	1,300	2,860	3,000	4,020	5,300	5,440	5,980	5,300	6,120
Ash	2,900	1,660	1,760	3,440	3,000	3,020	3,120	5,500	3,560	3,380	2,660	2,100	1,560
Balsam poplar	160	120	140	20	140	160	180	180	180	20	300	120	220
Cottonwood	120	360	80	80	500	40	60	140	20	40	0	160	80
Bigtooth aspen	1,220	640	900	520	1,880	1,840	2,220	1,320	960	1,040	860	520	420
Quaking aspen	3,280	2,740	2,480	3,660	5,640	4,420	4,680	3,400	2,620	3,300	2,300	1,960	1,320
Basswood	4,140	1,660	1,360	3,660	5,860	7,080	5,520	4,940	4,320	4,840	3,740	2,240	1,160
Yellow-poplar	60	0	60	240	0	20	60	80	0	200	40	0	160
Black walnut	40	20	140	240	0	0	0	0	0	40	140	20	0
Black cherry	1,960	1,760	2,160	2,400	3,160	3,100	1,660	2,300	2,340	1,800	1,240	1,240	600
Butternut	20	0	20	40	80	0	0	0	20	0	0	0	0
Elm	2,080	1,380	980	3,540	2,400	2,780	2,140	2,360	2,580	1,640	2,260	1,620	1,840
Paper birch	1,660	640	720	1,680	1,000	1,500	2,500	2,260	2,000	1,840	1,440	1,560	1,620
Other hardwoods	360	740	420	760	1,500	200	240	380	80	160	140	420	20
Noncommercial species	1,400	1,280	1,200	1,780	1,500	1,380	1,320	1,760	1,340	1,420	1,300	1,380	1,340
Total	81,260	29,280	40,020	63,620	73,520	87,380	89,140	91,300	89,560	94,120	91,840	92,260	92,780
All species	91,480	32,500	44,180	69,520	81,140	93,720	95,980	100,680	100,040	106,400	107,800	108,780	116,520
Number of plots	2,928	220	184	84	156	405	433	231	208	237	226	348	196
Standard error	740	1,580	1,860	3,380	2,440	1,480	1,600	2,160	2,420	2,120	2,380	1,860	2,660
Average basal area	99	39	54	86	93	105	106	107	105	110	112	113	118

[1] Forest type definitions and species list are in the appendix.

[2] Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Table 27.--Biomass yields per acre in all live trees by species group and stand-age class, Michigan, 1980[1/]

Aspen forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	640	360	420	740	820	440	680	480	1,160	800	1,560	4,280	1,580
Red pine	700	640	400	780	1,500	320	820	80	1,320	1,240	1,700	1,960	0
Jack pine	360	180	700	1,000	60	520	320	0	240	140	800	0	0
White spruce	960	260	300	1,560	860	1,400	1,300	2,260	840	1,480	1,160	2,140	0
Black spruce	240	80	80	440	80	380	720	80	20	480	0	480	500
Balsam fir	3,740	1,060	1,340	2,940	4,520	6,040	6,180	5,700	4,340	3,840	3,660	6,220	7,440
Hemlock	240	160	20	0	320	200	200	780	380	0	1,280	760	0
Tamarack	120	100	20	60	160	80	260	160	0	0	220	1,400	0
Northern white-cedar	1,740	360	440	1,520	1,200	1,520	2,100	2,720	4,300	3,420	8,080	9,180	17,940
Other softwoods	20	20	120	0	0	0	0	0	0	0	0	0	0
Total	8,760	3,220	3,840	9,040	9,520	10,900	12,580	12,260	12,600	11,400	18,460	26,420	27,460
Hardwoods:													
Select white oaks	400	360	300	140	200	300	700	160	980	100	1,360	380	0
Select red oaks	2,220	1,040	2,120	2,100	1,720	1,940	1,960	4,940	3,980	4,160	3,160	4,820	0
Other red oaks	140	40	160	280	160	220	160	0	220	100	320	0	0
Hickory	0	20	20	0	0	0	0	0	0	0	0	0	0
Yellow birch	280	40	100	0	360	460	500	400	160	240	1,140	0	0
Hard maple	2,000	980	580	940	2,620	2,520	2,240	2,800	4,860	6,420	2,460	1,620	0
Soft maple	5,340	2,680	2,960	2,540	6,260	6,720	7,860	8,860	6,820	7,180	6,080	6,040	8,260
Beech	140	120	60	240	280	280	20	320	0	0	260	0	0
Ash	1,040	300	660	900	1,860	1,420	980	980	2,240	1,320	1,660	3,780	1,620
Balsam poplar	2,940	720	1,140	3,180	3,180	4,300	3,400	2,880	3,920	5,440	6,800	16,860	12,160
Cottonwood	120	20	20	260	40	40	0	700	200	180	540	0	0
Bigtooth aspen	8,900	2,720	5,100	5,360	7,040	10,520	15,980	16,860	17,860	9,680	8,280	8,560	2,640
Quaking aspen	20,620	8,400	13,840	21,260	28,060	25,740	27,000	27,860	32,660	29,640	21,460	18,000	21,440
Basswood	320	120	40	140	320	420	300	240	1,060	500	2,320	1,380	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	600	660	860	1,380	340	440	540	300	640	260	1,040	480	880
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	440	140	500	320	400	800	660	260	380	200	140	1,020	0
Paper birch	3,860	1,180	1,660	2,800	3,860	5,160	5,760	7,180	4,640	7,020	5,920	7,700	4,840
Other hardwoods	60	40	80	40	80	40	60	120	340	0	0	0	0
Noncommercial species	300	280	280	640	360	280	140	420	320	520	100	560	0
Total	49,720	19,860	30,480	42,520	57,140	61,600	68,260	75,280	81,280	72,960	63,040	71,200	51,840
All species	58,480	23,080	34,320	51,560	66,660	72,500	80,840	87,540	93,880	84,360	81,500	97,620	79,300
Number of plots	1,529	325	252	65	133	239	222	118	64	48	34	25	4
Standard error	1,000	1,120	1,400	3,460	2,740	2,160	2,240	3,440	4,380	4,700	5,880	7,780	22,740
Average basal area	73	31	46	69	84	93	98	104	108	97	101	114	119

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

Paper birch forest type - All site index classes

(In pounds per acre green weight)

Species group	Average[2/]	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
Softwoods:													
White pine	840	0	120	360	1,340	1,200	360	680	1,580	3,740	2,600	1,640	0
Red pine	640	240	0	140	1,320	580	240	680	2,280	0	2,340	0	0
Jack pine	540	0	0	0	0	0	1,840	100	0	2,500	0	0	0
White spruce	1,360	1,020	240	0	1,040	3,580	840	1,320	1,200	2,880	1,400	1,540	2,840
Black spruce	440	80	0	300	1,020	240	100	520	2,200	540	0	0	1,000
Balsam fir	5,800	1,900	2,860	6,900	11,660	6,020	5,660	5,240	4,700	8,320	8,900	5,980	13,540
Hemlock	580	0	600	100	480	260	1,120	180	900	0	0	7,520	0
Tamarack	140	380	20	0	0	0	280	0	40	0	0	0	2,000
Northern white-cedar	4,700	2,520	2,580	6,440	3,820	1,620	4,900	5,180	9,360	10,160	7,660	3,220	3,920
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15,040	6,140	6,420	14,240	20,680	13,500	15,340	13,900	22,260	28,140	22,900	19,900	23,300
Hardwoods:													
Select white oaks	140	0	0	0	680	0	320	140	0	0	0	0	0
Select red oaks	1,440	240	0	0	360	2,120	2,580	380	2,800	6,560	0	0	1,000
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	20	0	0	0	0	0	100	0	0	0	0	0	0
Yellow birch	700	0	200	0	860	340	760	460	280	3,580	1,340	12,620	0
Hard maple	4,200	560	2,760	120	800	6,480	3,480	5,140	5,640	13,360	1,100	0	16,160
Soft maple	8,420	2,980	2,320	2,360	7,400	10,780	12,080	6,620	8,140	13,940	13,040	21,200	8,060
Beech	300	0	0	0	0	420	840	280	20	0	0	0	0
Ash	1,280	0	380	2,820	2,380	840	1,660	1,980	1,600	0	0	0	0
Balsam poplar	900	380	180	0	720	780	1,440	1,420	160	700	0	0	3,640
Cottonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigtooth aspen	1,540	920	0	660	1,140	1,500	900	2,240	3,500	4,060	3,880	0	0
Quaking aspen	5,740	1,160	2,960	5,200	6,680	7,800	5,720	6,280	7,680	1,700	10,120	5,580	8,200
Basswood	720	0	440	0	2,220	2,040	1,040	100	220	0	0	0	0
Yellow-poplar	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	0	0	0	0	0	0	0	0	0	0	0
Black cherry	280	0	760	0	280	440	360	100	0	760	220	0	0
Butternut	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	220	0	180	520	280	440	80	280	0	720	380	0	0
Paper birch	34,100	12,480	16,400	22,820	24,540	33,940	44,340	39,440	36,860	40,560	37,020	52,280	46,080
Other hardwoods	20	0	0	0	60	0	0	120	0	0	0	0	0
Noncommercial species	560	20	80	460	380	460	620	0	620	920	6,360	0	0
Total	60,580	18,740	26,660	34,960	48,780	68,380	76,320	64,980	67,520	86,860	73,460	91,680	83,140
All species	75,620	24,880	33,080	49,200	69,460	81,880	91,660	78,880	89,780	115,000	96,360	111,580	106,440
Number of plots	190	15	18	6	13	23	45	36	15	6	7	2	4
Standard error	2,800	5,320	5,780	9,160	7,720	6,540	4,740	6,080	10,180	9,920	10,800	11,660	9,080
Average basal area	94	38	47	75	89	103	113	98	108	124	112	116	117

1/ Forest type definitions and species list are in the appendix.

2/ Weighted average over all stand-age classes--the average biomass per acre for all ages in the forest type and index range.

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Hahn, Jerold T; Stelman, Joan M.
Empirical yield tables for Michigan. Gen. Tech. Rep. NC-96. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 33 p.

Describes the tables derived from the 1980 Forest Survey of Michigan and presents ways the tables can be used. These tables are broken down according to Michigan's four Forest Survey Units, 14 forest types, and 5 site-index classes.

KEY WORDS: Inventory, volume, growth.

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General Technical
Report **NC-97**

Pilot Testing a New System For Appraising Wildfire Effects in Wisconsin

David C. Baumgartner

Baumgartner, David C.
Pilot testing a new system for appraising wildfire effects in Wisconsin. Gen. Tech. Rep. NC-97. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 6p.

Describes the results of pilot testing a new wildfire effects appraisal system in Wisconsin.

KEY WORDS: Economic values, fire management, valuation procedures, fire damage, fire benefits.

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PILOT TESTING A NEW SYSTEM FOR APPRAISING WILDFIRE EFFECTS IN WISCONSIN

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In Wisconsin, wildland fire damage appraisals conducted by Department of Natural Resources (DNR) oresters are frequently used in insurance settlements nd legal proceedings. Using their old fire damage ppraisal system, developed in 1938, fire management fficials called upon for court testimony were often mbarrassed by the poorly supported values that the ystem yielded. The old system had severe limitations or appraising immature timber stands, particularly lantations. Another problem was the arbitrary ssignment of $1 of loss per acre for recreation and vildfire and another $1 loss per acre for site deterioration. No specific instructions were provided for ppraising damage to crops, equipment and improvements, ornamental trees, aesthetics, environmental uality, or developed recreation.

Recognizing these shortcomings, the Wisconsin DNR, in conjunction with the North Central Forest Experiment Station and Michigan State University, leveloped an improved system. The primary purpose f the new system is to provide consistent and ccurate wildfire effects appraisal information that vould be defensible in court. The system was lesigned to be reasonably simple, to take no more han 1 hour to complete for an average fire, and to nake the best possible use of currently existing Visconsin data.

A tentative draft of the new system was completed n 1979. In 1980 a selected group of Wisconsin DNR presters was trained to use the new system. During he 1980 and 1981 fire seasons they used both the old nd the new systems to estimate the economic effects f a sample of Wisconsin fires.[1]

This report first compares the values obtained with ach system and then describes the problems encountered during field testing and subsequent evaluations.

[1]*A detailed handbook, available from the North entral Forest Experiment Station, describes step by ep field data collection and office calculation procedures for the new system.*

COMPARING THE OLD AND NEW SYSTEMS

The Sample

A total of 611 fires was included in the sample. They occurred in 21 counties selected to represent the full range of Wisconsin cover types. These fires burned a total of about 3,002 acres for an average of 4.9 acres per fire. However, excluding one large fire (1,028 acres), total acreage burned was only 1,974 or an average of 3.2 acres per fire. Only 50 of the other fires exceeded 10 acres, and only 7 exceeded 50 acres. The number of fires affecting various cover types were:

Cover type	Fires (Number)
Red pine	34
Jack pine	21
Aspen	17
White birch	4
Northern hardwoods	33
Other timber	35
Open field	384
Marsh	26
Crop	61

Resource Elements

The new system includes the following seven resource elements or value components:

- Timber
- Wildlife
- Recreation
- Ornamental trees
- Environmental quality
- Crops
- Equipment and improvements.

Recreation is divided into effects on aesthetics and effects on developed recreation sites. Effects on undeveloped recreation are incorporated into the wildlife element. Because the primary purpose of the system is to ensure credibility in court, value changes

for most of the resource elements are expressed in terms of their impact on individual owners. Value changes for wildlife, aesthetics, and environmental quality, however, are expressed in terms of the impact on the general public because landowners cannot capture all of the value of these elements.

Timber

The new appraisal system for timber values differs from the old in several ways. One difference is that the old system defined the cover type as the prevailing species. Volume and value of affected trees were then estimated from tables based on pure stands of the prevailing species. The new system estimates volume and value of affected trees from tables based on the average mix of species found in a predominant cover type in various districts of Wisconsin. Another difference is in the estimation of tree mortality. The old system judged the degree of tree mortality for each burn as light (50 percent mortality), moderate (75 percent) or severe (100 percent). The new system estimates tree mortality as a function of the percent of crown scorched (for conifers) or the height of bark scorched (for immature and merchantable hardwoods), and can be expressed as any percentage between 0 and 100. Another major difference in the systems is that the old estimates current value for merchantable stands and discounts immature stands from the projected value they would have at optimum rotation age. The new system also estimates the current value for merchantable trees but for immature timber the harvest date is assumed to be the date at which the trees will first become merchantable rather than the "optimum" rotation age. Using this shorter period reduces prediction problems as well as the importance of the choice of discount rate.

Of the 611 fires included in the sample, 204 had an impact on timber. The new system produced consistently lower values for timber, an average of $41.77 per acre, compared to $70.00 per acre using the old system. This difference results from the old system's provision of assigning an arbitrary mortality estimate of 50 percent for a light burn, 75 percent for a moderate burn, and 100 percent for a severe burn. The average mortality estimate for light burns obtained with the continuous mortality function of the new system was 30 percent for light burns, 41 percent for moderate, and 66 percent for severe. Thus, overall values for all timber were lower with the new system even though it tended to produce higher values for immature timber damage due to the assumption that timber would be harvested when it first became merchantable rather than at optimum rotation age.

Wildlife

In contrast to the old system that arbitraril assigned a wildlife value loss of $1 per acre burne the new system provided a method to estimate th variable economic impact of fires on wildlife. Whi recognizing that wildlife is valuable for many no economic reasons, the new system assumes that mo of the economic value is associated with outdo recreation, primarily hunting for game species. Fis are usually unaffected by wildfire in Wisconsin.

If a sample fire occurred in a cover type importa to deer, small game, or waterfowl, the economic lo and/or benefit was estimated using the basic formul

$$\text{loss or benefit} = \text{use change} \times \text{wildlife loss or benefit factor.}$$

Use change is a function of tree mortality and th size of the burned area. Wildlife loss and benef factors were developed for each county in Wisconsi An example of loss and benefit factors from th southern region of Wisconsin is given in table 1. Eac factor is the product of the success index for particular species and county, the average expend ture for a day spent hunting that species, and the fu effect of the fire on game populations. Generally, th success index is a ratio of use per acre in a county the average use per acre in Wisconsin. Thus, a succe index of one indicates average use, while a tw indicates twice the average use. Estimates of the 198 value of a user day based on hunter expenditur (National Analysts 1975) were $38.06 for deer hun ers, $11.49 for small game hunters, and $20.61 f waterfowl hunters. The full effect for timbered are is the change in game population expected if all tre were killed. The full effect is also assumed for op fields.

Benefits to white-tailed deer (in the form of i creased browse) accrue when fires occur in whi birch and northern hardwood stands or in jack pi and red pine plantations. Losses occur when the fire in a spruce-fir, black spruce, tamarack, or cedar typ Fire effects on small game species (rabbit, pheasan grouse) are primarily beneficial and result from fir in black spruce, white birch, aspen, jack pine, an open fields. Waterfowl benefit from fires in marsh or open fields within one-quarter mile of water, b are harmed if the fire occurs during the nestin season between April 15 and July 31.

Of the 611 fires included in the sample, 345 burn cover types important to wildlife and thus had a economic impact. Of these fires, 22 had an impact deer, 273 on small game, and 250 on waterfow

Table 1.—*Wildlife loss and benefit factors in Wisconsin*

(In dollars/acres)

Region and County	Deer		Small game			Waterfowl	
	Benefit	Loss	BS.WB	A. JP	Open field	Benefit	Loss
Southern							
Columbia	308.71	214.38	2.60	1.98	12.21	15.52	3.10
Dane	58.80	34.12	6.64	10.34	6.99	5.57	1.11
Dodge	9.60	11.37	2.49	14.02	24.67	36.76	7.35
Fond du Lac	8.80	34.12	2.49	14.02	24.67	36.76	7.35
Grant	19.60	11.37	1.02	1.98		3.60	.67
Green	19.60	11.37	12.49	14.02	24.67	1.04	.21
Green Lake	308.71	214.38	6.64	6.94	24.67	36.76	7.35
Iowa	214.39	124.41	1.02	4.35	2.76	3.60	.67
Jefferson	19.60	11.37	6.64	6.94	12.21	36.76	.38
Lafayette	19.60	11.37	12.49	14.02	12.21	1.04	.21
Marquette	308.71	214.38	1.02	1.98		15.52	3.10
Richland	143.34	83.17	6.64	10.34		1.04	.21
Rock	19.60	11.37	25.47	29.08	24.67	5.57	1.11
Sauk	214.39	124.41	6.64	6.94		3.60	.67

Beneficial impacts resulted on 342 of these fires and losses (primarily for waterfowl) occurred on 144. The net economic effect of the fire was beneficial on 341 of the 345 fires and a net loss occurred on only 4. The average net benefit per acre burned was \$8.86 for deer, \$5.56 for waterfowl, \$3.63 for small game, and \$7.31 for all wildlife. This represents a sharp contrast from the \$1 per acre loss used for all fires with the old system.

Recreation

No specific instructions were provided in the old appraisal system for estimating the economic impact of wildfire on developed recreation sites. The new system is based on an estimate of the number of visitor groups that would have used a fire-damaged recreation site during the remainder of the season (from time of fire to December 31) and the value per visitor group day for various recreational activities. Based on a Wisconsin DNR survey of expenditures in 1969 and inflated to 1982 dollars, the values used were:

Sightseeing —	\$35.57
Camping —	33.85
Fishing —	31.61
Picknicking —	25.88
Boating —	21.36
Hiking —	20.50
Swimming —	14.42

None of the 611 fires included in the sample had an economic impact on developed recreation sites.

Aesthetics

Although no attempt was made to put dollar values on the effects of wildfire on aesthetics, the new Wisconsin system provides a consistent procedure to determine the relative impact. Variables influencing the aesthetic effect are the size of the area burned, the aesthetic importance of the area, and the intensity and duration of the effect. Five recreation use classes were identified to rate the relative aesthetic importance of the burned area.

One criterion for selecting the appropriate use class is the type of road from which the burned site can be seen. The highest category is a site visible from a four-lane highway while the lowest category is a site that cannot be seen from any road. A second criterion is the general recreational use of an area from which the fire site is visible. Lakes with public access and developed sites such as campgrounds and picnic areas are in the highest category. The lowest category is used for burned areas that cannot be seen from any road, trail, lake, or stream.

The intensity and duration of the fire's effect is assumed to be related to tree mortality, which is expressed in terms of four categories ranging from <25 to 100 percent. Aesthetic effects are rated as extreme, very heavy, heavy, moderate, light, or

negligible. Of the 611 sample fires, 521 had a negligible aesthetic impact, 46 were low, 29 were moderate, 13 high, 1 very high, and 1 large fire of more than 1,000 acres was rated extreme.

Ornamentals

Many Wisconsin wildfires occur near residences or developed recreation sites where they damage ornamental trees. Because ornamentals are not sold as timber, it is not appropriate to appraise them on the basis of timber values as was done with the old system.

The new system appraises small trees and shrubs at nursery replacement costs. The value of each large tree or group of similar trees is estimated using the following formula: value = base value x species factor x condition factor x location factor. This formula was developed by the International Shade Tree Conference in 1969 (Michigan Forestry and Park Association 1978). The base value used in Wisconsin is $19.81 per square inch. This value is obtained from $9.00 per square inch determined at the International Shade Tree Conference in 1969, inflated to 1982 dollars. The species factors assign each species a factor of 0.25, 0.50, 0.75, or 1.0 according to its desirability as an ornamental. The condition factor is a relative rating, between zero and one, of the prefire health, form, and vigor of the affected tree. The location factor is an assessment of the importance of the ornamental tree in the landscape, ranging from one for a single specimen on a key site to near zero for one of a group of trees at the forest edge of a developed site. All trees must be visible from and within 100 yards of a lake, home, or developed recreation site to be considered ornamentals.

Of the 611 sample fires, 36 damaged a total of 1,160 ornamental trees with an average damage of $51.45 per tree, or $1,658 per fire affecting ornamentals. This figure is much higher than the insignificant one obtained by using the old system and shows that ornamental trees are an important component of wildland fire damage in Wisconsin.

Environmental Values

Wisconsin data indicate that water quality and soil stability are rarely significantly affected by a single fire. However, air quality can be affected by smoke, but was not considered in the old system. Although no dollar value is assigned, the new system employs a method to estimate the relative importance of smoke on air quality.

The method requires determining atmospheri stability (stable or unstable), a smoke index, and population use class. The smoke index is based both o the size of the fire and the duration of the smoke. Thu a small but long-burning peat fire might produce higher smoke index than a large grass fire. Fiv population use classes were identified to rate th importance of use areas affected by the smoke. Th classes generally depend on the size of the city or tow in which the smoke can be detected, although high way size and recreation use can also influence th classification. The effects are rated as extreme, sever heavy, moderate, light, or negligible. Of the 61 sample fires, 324 had negligible impacts on air qual ity, 204 had light impacts, 72 had moderate, and onl 11 were heavy.

Crops

The old system contained no instructions for esti mating wildfire damage to crops. With the nev system, the loss of a crop is simply the net value of th expected yield (as estimated by county agents). If th burned crop can be replanted in the current year, th loss is the sum of the replanting cost and the value o the reduction in the expected yield (the replanted cro would probably have a reduced yield due to a shorte growing season). In either case the following equatio can be used:

$$\text{crop loss} = \text{replanting cost} \times \text{acres burned} + \text{yield loss} \times \text{price} \times \text{acres burned.}$$

If a crop cannot be replanted in the current year, th replanting cost is zero.

Of the 611 sample fires, 61 burned a total of 22 acres of cropland (mostly hay) and did an averag damage of $9.49 per acre of cropland burned.

Equipment and Improvements

In contrast to the old system that contained n specific instructions for estimating damage to equip ment and improvements the new system estimates th cost to replace destroyed items or to restore a dam aged item to its prefire condition. Foresters in th field decide which items require repair or replace ment and estimate their prefire condition. The cost o the repair or replacement is determined in the offic after consulting blue books, contractors, or equipment dealers.

Of the 611 sample fires, 71 resulted in damage to equipment or improvements. The average damage for these fires was $826.44 but this average was greatly

raised by one fire that caused nearly $20,000 worth of damage to equipment and improvements. Without that fire, the average damage was $570.03. Like ornamentals, equipment and improvement losses can be an important component of the total net value change of a fire.

PROBLEMS WITH THE NEW SYSTEM

Each Wisconsin DNR forester who used the old and the new system in the sample of 1980 and 1981 Wisconsin fires was asked to evaluate the new system and discuss the need for changes and improvements. Although these foresters were pleased with the new system and all thought that it was a great improvement over the old, they had several problems in using it.

Tree Mortality Equations and Graphs

The new system's tree mortality estimation equations and graphs, developed by Gorte (1981), were tested during the Wisconsin fire season of 1980. Users found that Gorte's equations performed well for Wisconsin conifers but not for hardwoods. Part of the problem was due to the difference in Wisconsin species and part due to the fact that Gorte's hardwood equations were only for merchantable and immature trees rather than for a full range of diameter classes. A study is underway to develop new hardwood mortality equations, based on variables that can be measured shortly after fires.

The participants were also concerned that the new system contained no provision for estimating volume and value losses for trees that were damaged but not killed, nor did it account directly for salvage values for dead and severely damaged trees. These problems are being addressed in studies by the North Central Forest Experiment Station.

Black Walnut, Christmas Trees, and Plantations

Trial participants pointed out that values obtained with the conventional timber methodology (based on the average mix of species in a timber type) were far too low for black walnut, Christmas trees, and plantations of conifers or black walnut. In several cases the values obtained for plantations were lower than the replanting cost. These problems were resolved by developing a separate value table for black walnut and by assigning individual tree rather than volume per acre values to Christmas trees. For plantations, site preparation costs were included in the loss calculation and replanting costs were reported although not included in the loss calculation. This represents an interim compromise because it is still debatable if either site preparation or replanting costs are a legitimate addition to the value loss. The fact that these costs sometimes exceeded discounted future market values may indicate that additional nonmarket values are incorporated in the decision to establish a plantation. Thus, the procedures for evaluating fire effects on plantations may be revised again.

Wildlife

Many who tried the new system were uncomfortable with the wildlife section. One general concern was that the values obtained with the new system (or any system) may not be accurate enough to be useful. Some felt that it is inherently wrong to try to put price tags on wildlife. Their reasoning paralleled that expressed by Leopold (1962). "One basic weakness in a conservation system based wholly on economic motives is that most members of the land community have no economic value. Wildflowers and songbirds are examples. Of the 22,000 higher plants and animals native to Wisconsin, it is doubtful whether more than 5 percent can be sold, fed, eaten, or otherwise put to economic use."

The wildlife effects appraisal procedures are based on only one of many fairly subjective approaches, none of which is universally accepted. The simplifying assumption that most of the economic value of wildlife is reflected in hunter expenditures seems necessary to develop any dollar figures at all, given the data available in Wisconsin. If the wildlife values obtained using the new system provide a consistent means of estimating the relative impact of different fires on wildlife, and the results are at least in the right direction in terms of benefits and damages, the new system is an improvement. Researchers generally agree that the physical effects of fire on wildlife in Wisconsin are variable but mostly beneficial. The results of using the new system reflect this, but the old assumes that effects are uniform and moderately harmful.

Specific problems mentioned by users involved the waterfowl calculation and the complexity of the calculations for small game. The instructions for the waterfowl calculation originally required the appraiser to make the calculation for all open fields and marsh lands within 1 mile of water. In Wisconsin nearly all of the sample fires involving open fields or marsh were within the 1-mile criterion. This criterion was therefore reduced to one-quarter mile on the advice of DNR wildlife biologists.

To reduce the complexity of the small game calculations, which were originally calculated individually

for pheasants, grouse, and rabbits, these were combined into one average factor for small game. The average benefits and losses for each county in Wisconsin were then pre-calculated and arranged in a table. The appraisers now have only to refer to the table if a fire occurred in a cover type important to wildlife.

Ornamentals

The trial participants experienced problems involving both very small and very large ornamental trees using the formula for ornamental trees developed by the International Shade Tree Conference (Michigan Forestry and Park Association 1978). For small trees, the values obtained were consistently lower than nursery replacement costs. For large trees the d.b.h.^{2} element in the formula resulted in unrealistically high incremental value increases when trees exceeded 14 inches in diameter. To correct these problems, the new system was changed to use nursery replacement costs for all small trees and shrubs, and the value for a 14 inch tree was assigned to all trees 14 inches and over.

Another problem occurred on several fires that damaged trees on undeveloped lots. The original instructions defined an ornamental tree in terms of its location in a yard within 100 feet of a home, or visible and within 100 feet of a developed recreation site. Users felt that the trees on undeveloped lots were more valuable than a timber estimate would indicate but less valuable than an ornamental tree (as defined above) estimate would indicate even if a minimum location class of 0.25 was used. The system was revised to allow classification of trees on undeveloped lots as ornamentals at the discretion of the appraiser and to allow him/her to assign a location class lower than 0.25.

Crops

Users experienced no problems in applying the new system to fires that damaged farm crops. They did feel, however, that a potential problem exists for crops that are not planted and harvested annually such as fruit and ginseng. It was decided, however, that this problem would not occur often enough to merit specific treatment in the new system other than assigning a space for foresters to describe any value changes not specifically covered by the instructions.

General

While testing the new system, users found many ways to streamline both the reporting forms and the instruction guidebook and make them easier to use. Several sections that required calculations were con verted to tables or charts. An improved flow char was designed to bypass sections not needed on particular fire and to proceed through the appraisa as quickly as possible without retracing any steps.

SUMMARY

The new system provides a consistent and compre hensive methodology for appraising the full range o fire-related resource effects. It recognizes the benef icial effect of fires as well as the damages, and i utilizes the most current information available t estimate value changes. The cooperative developmen of the new system attempted to strike a balanc between a theoretically correct system and one that i practical and easy to use. It represents a step forwar in the evolution toward a complete and theoreticall correct system and is flexible enough to accommodat changes as more current information becomes avail able. Although many of the inputs to the system, suc as hunter success indices and timber types or prices were used because of their availability in Wisconsin similar data for many other Northeastern States ar probably available and the basic format should b generally useful. Researchers in West Virginia ar currently studying the adaptability of the Wisconsi system to that State.

Some problems with the system remain and others are likely to turn up as results of implementing th system statewide in 1982 are analyzed. Probably th most important problems are the uncertain accurac of the tree mortality prediction equations in Wiscon sin hardwood timber types and the lack of a method t estimate the value loss for trees injured by a fire. Researchers at the North Central Forest Experiment Station are developing improved mortality predictio equations and a method to predict the potential valu loss for fire-injured trees.

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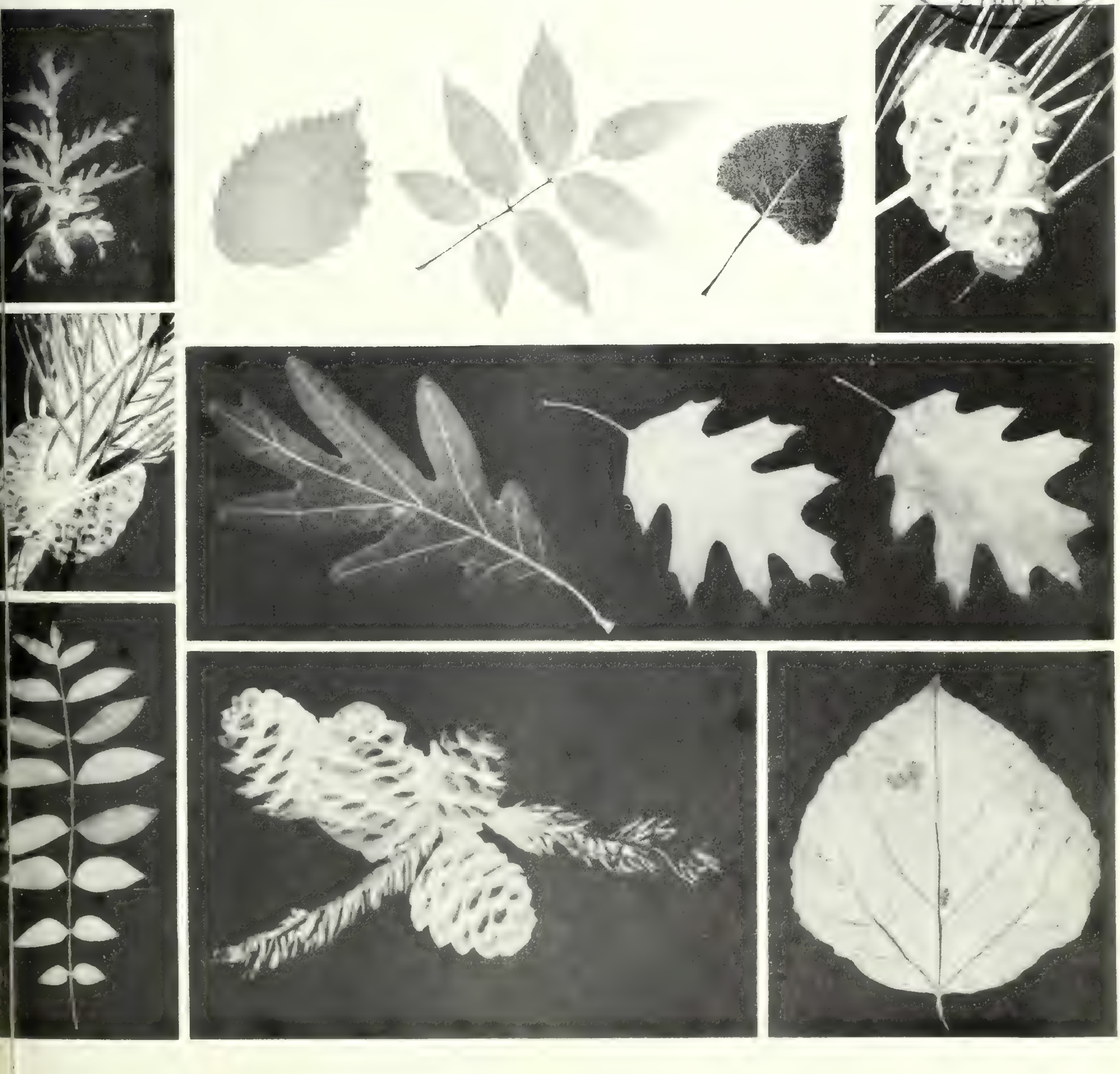
General Technical Report **NC-98**

Manager's Handbook for Elm-Ash-Cottonwood in the North Central States

Charles C. Myers and Roland G. Buchman



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FOREWORD

This is one of a series of manager's handbooks for important forest types in the North Central States. The purpose of this series is to present the resource manager with the latest and best information available on managing these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The authors have, in certain instances, drawn freely on unpublished information provided by scientists and managers outside their specialty. They are also grateful to several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find, in logical sequence, the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important types can be continually improved.

CONTENTS

MANAGER'S HANDBOOK FOR ELM-ASH-COTTONWOOD IN THE NORTH CENTRAL STATES

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DEFINITION OF TYPE

Elm-ash-cottonwood (E-A-C), a forest type recognized by the Renewable Resources Evaluation Group of the U.S. Forest Service, is comprised of the following Society of American Foresters cover types (SAF number): black ash-American elm-red maple (39); silver maple-American elm (62); cottonwood (63); sugarberry-American elm-green ash (93); sycamore-sweetgum-American elm (94); and black willow (95). Many associated species are found in these moist site, bottomland hardwood stands.

A stand will be recognized as E-A-C if more than half of the basal area (or stem count if seedlings and saplings make up the whole stand) is composed of tree species named in the six associated SAF types.

SILVICAL HIGHLIGHTS

Elm-ash-cottonwood is found on alluvial soils along rivers and streams throughout the North Central States. The type is common on land subject to annual flooding and can survive flooding during as much as 50 percent of the growing season. A subclimax type, it follows pure cottonwood and willow stands. These pioneer species become established wherever sufficient light and moist bare soil are available. Cottonwood outgrows willow and becomes dominant forming two-storied stands, unless extended flooding during the growing season kills back the more susceptible cottonwood. Cottonwood and willow cannot regenerate under shade and are gradually replaced by more tolerant species including silver maple, American elm, green ash, sycamore, and river birch. In the southern part of the range sweetgum and hackberry are common.

To obtain natural reproduction of major species in the association, certain sites are required. Cottonwood, river birch, willow, and sycamore have light seed that can be borne for considerable distance by wind and water, but will remain viable for only a few days. These seeds require mineral soil exposed to direct sunlight for germination. Open sites with siltation from flooding are excellent for natural establishment.

American elm, green ash and silver maple seed can germinate on moist litter as well as on mineral soil. These species make best early growth in partial shade. They often regenerate profusely from either seed or vegetatively after cutting or disturbance. While Dutch elm disease has practically eliminated mature elms from the type, seedlings and saplings are abundant. Trees as young as 15 years produce seed.

As many as 50 species having some commercial importance are associated with the elm-ash-cottonwood type. Factors such as fire, cutting, flooding, insects, disease, and natural succession cause frequent rapid changes in species composition. Elm-ash-cottonwood is a pioneer to intermediate type that cannot be maintained without management or natural disturbance. Flooding and timber removal are important conditions for its establishment and continued existence.

MANAGEMENT OBJECTIVES

Production of high value sawtimber and veneer is the primary management objective. It is met primarily in the final harvest, which emphasizes sawtimber and veneer logs.

A secondary objective is the production of wood for paper, fuel, and other products. Intermediate thinnings may produce large quantities of material for these secondary products.

A tertiary objective is to provide for other uses of these valuable sites, including food and shelter for wildlife and waterfowl, watershed protection and erosion control, and a variety of recreation activities. Generally, these values are enhanced by timber harvesting and management. However, harvesting practices may require modifications should certain values—such as esthetics—predominate. Details on how to meet these management objectives are given throughout the text.

Regardless of the purpose of management, the primary vegetative, soil, and water resources must be protected. Site protection during timber harvest—especially erosion control—is needed in addition to protecting the timber from insects, disease, and fire. These protection guidelines are appropriate where management doesn't emphasize timber production.

KEY TO RECOMMENDATIONS

Recommendations are given for applying silvicultural practices appropriate for the specific conditions of a stand. These recommendations are based on the best management and silvicultural information currently available. They should be considered a guide and not a substitute for on-the-ground observations and management experience. All possible stand conditions cannot be described; the manager must select the practice best suited for the particular situation. Additional research is needed to improve management of this important type on very productive river bottom sites.

The key is based primarily on stand basal area, number of trees per acre, and site quality and tree diameter. Inventory practices for estimating these variables are well established and are not presented in detail in this handbook.

When using the key, start with the first pair of numbered statements and select the statement that best describes the stand to be managed. The selected statement will direct you either to another pair of numbered statements or to a management prescription for the stand. References are also given by page number within the text to provide more detailed information for the prescription.

1. Stand site index 70 or greater .... (p. 3) ...2
1. Stand site index less than 70 .... MANAGE FOR NON-TIMBER RESOURCES (p. 6) DO NOT MANAGE FOR TIMBER
   2. Dominant-codominant trees average 24 inches d.b.h. or more .... CLEARCUT (p. 3) ...3
   2. Dominant-codominant trees average less than 24 inches d.b.h. 4
3. Source of regeneration for desired species is present .... DO NOTHING, REGENERATION IS EXPECTED ...(p. 3, 5)
3. Regeneration source missing .... PREPARE SITE AND PLANT ... (p. 5)
   4. Stand contains patches at least 2 acres where dominant-codominant trees average 24 inches d.b.h or more ... PARTITION? ...... (p. 4) ... 5
   4. Stand contains no patches ready for final harvest 6
5. To manage mini-stands ... CLEARCUT PATCHES OF MATURE TREES (p. 3) ...... 3 TREAT UNCUT AREA AS SECOND STAND ... (p. 4) 6
5. To manage as one stand 6
   6. Stand is fully stocked, exceeds B-line in stocking guide (Appendix) .. THIN TO PRESCRIBED RESIDUAL BASAL AREA ... (p. 4, 10)
   6. Stand is understocked 7
7. Site is suitable for establishing new stand .... CLEARCUT WHEN MERCHANTABLE (p. 5, 3) 3
7. Site not suitable for new stand .... MANAGE FOR NON-TIMBER RESOURCES .... (p. 6)

TIMBER MANAGEMENT CONSIDERATIONS

Elm-ash-cottonwood is confined to river and stream floodplains. Major river stands may be several miles in width, while on smaller streams the stand will be confined to a narrow strip. Managing for timber in narrow stands can severely interfere with other uses of the land by creating erosion problems and eliminating wildlife habitat.

Stand Size

There is no silvicultural reason to restrict maximum stand size though size may be important to consider for esthetics and uses other than timber. However, if natural reproduction is desired a minimum stand size of two acres is recommended. Natural reproduction of most of the desirable bottomland hardwoods (which are shade intolerant) requires full sunlight, so harvesting should provide the forest openings needed for establishing the new stand. Remember that the smaller the opening the greater the amount of its area that is shaded by the surrounding unharvested stand (the "edge effect").

In addition to avoiding excessive edge effect, managers should assure that stands are large enough to warrant mapping and record keeping. Small stands are readily managed and recorded within small forest

holdings but may become a burden on large ownerships. Stands should be relatively uniform in site and vegetation and be easily identified on the ground.

Site Quality

Most E-A-C stands occur on very productive sites—site index 70[1] or more. Sites with an index less than 70 should be considered for uses other than timber.

Determine site index from single-stemmed dominant or codominant trees of the most frequently occurring species on the site. However, when management objectives emphasize particular species, trees of those species should be used.

Height-age measurements should be taken from several trees on each site. Use local site index curves if possible to determine site quality. Otherwise, use the general curves provided for the more common species (Appendix).

Site—Species Relations

Bottomland hardwood sites are complex communities where slight changes in elevation can result in considerable differences in flooding and drainage conditions, soils, and tree species. Of course, the changes are most rapid at right angles to the river rather than parallel to it. Site requirements for common species in the type are summarized below.

Species	Site Requirements[2]
American elm	Common on wet flats and bottomlands throughout the range. Found on soils ranging from coarse sands to clays, but does best on rich, well-drained loams. Seedlings become established on moist litter or mineral soil in partial shade.
Green ash	Common on alluvial soils along rivers and streams throughout the range. Found where good moisture conditions occur in medium-to-coarse textured sands and loams and in clays. Seedlings become established on moist litter or mineral soil in partial shade.
Eastern cottonwood	Common on moist alluvial soil throughout range. Found on soils ranging from coarse sands to clays but makes best growth on fine sandy loam near streams. Seedlings require moist exposed mineral soil and full sunlight for establishment.
Silver maple	Common on alluvial flood plains of major rivers. Found on moist, fine textured silts and clay soils that are imperfectly drained. Seedlings require moist litter or mineral soil and full sunlight for establishment.
Black willow	Common on lower, wetter, less sandy sites along river and stream bottoms throughout range. Pioneer species, intermediate in succession. Found on wide range of soils from sands to clays. Seedlings require very moist exposed mineral soil and full sunlight for establishment.
American sycamore	Sycamore is common on moist alluvial soils along rivers and streams throughout range. Found on wide variety of soils from sands to clays with good moisture supply. Seedlings require moist, exposed mineral soiland full sunlight for development.
River birch	Common on alluvial soils along rivers and streams throughout range. Found on silts and clay soils with imperfect drainage. Seedlings require moist, exposed mineral soil and full sunlight for development.

[1]*Substitute 60 if American elm is used to determine site index.*

[2]*From USDA Forest Service (1965).*

Controlling Stand Harvest

Both the timing and method of stand harvesting affect the timber produced and the new trees established. The timber value and growth rate of the species present and the shade tolerance of the desired reproduction must also be considered (table 1).

Mature Stands

An elm-ash-cottonwood stand is biologically mature and ready for final harvest when dominant-codominant trees average 24 inches in diameter. If the stand is composed primarily of river birch, use 18 inches as the critical diameter; with elm, 20 inches.

Table 1.—*Growth, timber value, and shade tolerance of bottomland hardwood species*[1]

Species	Shade tolerance	Growth rate	Timber value
Green ash	Intolerant	Medium	High
River birch	Intolerant	Low-medium	Low
Cottonwood	Intolerant	Excellent	High
American elm	Intermediate	Medium	Low
Hackberry	Intolerant	Medium	Low
Red maple	Intermediate	Medium	Moderate-low
Silver maple	Intermediate	Medium	Moderate-low
Sweetgum	Intolerant	Medium-good	Moderate
Sycamore	Intolerant	Good-excellent	Moderate
Black willow	Intolerant	Excellent	Moderate

[1]Based on Garrett 1982 and Putnam *et al.* 1960.

Most mature stands will not produce the timber quality and growth that young stands would on the site. Mortality and cull will be increasing. By harvesting the old stand and establishing a new one you can get a higher average annual production and perhaps a better species mix.

A well managed, fully stocked, mature stand will yield from 15,000 to 18,000 board feet per acre (International ¼-inch scale) and 5 to 6 cords of topwood from the harvest cut (table 2).

Clearcut for the final harvest. This not only efficiently removes all products, but creates the opening necessary for establishing a new stand of intolerant species.

Table 2.—*Cumulative yields per acre for well-managed stands on good sites*[1]

Average d.b.h.[2]	Sawtimber: Standing crop	Sawtimber: Previous thinnings	Poletimber	Topwood
	Board feet[3]		*cords*	*cords*
6	0	0	5.3	0.0
10	0	0	11.8	0.0
14	5,196	0	18.8	6.8
18	10,623	0	18.8	12.7
22	14,699	1,705	18.8	18.2
26	18,243	3,876	18.8	23.2

[1]From Putnam *et al.* 1960.
[2]Average diameter of dominant and codominant trees.
[3]Doyle rule.

Diverse Stands

Even though the whole stand is not mature, portions of it may be ready for final harvest. Delaying the harvest will lead to loss of productivity from mortality and perhaps an excessive decline in quality. Although clearcutting the whole stand would benefit the mature portion, it would sacrifice the young, developing portions of the stand.

This diverse stand, in essence, may be better considered as two stands. A large stand could readily produce two or more stands meeting the stand size criteria, and result in more homogeneous management units.

The newly delineated mature stand should be clearcut. This introduces a different management cycle from the immature stand and will stretch out the timber harvests, while not sacrificing timber production.

Management of the newly delineated immature stand should be for high quality trees.

If a stand is too small to produce two units, you should consider the relative sizes of the mature and immature segments. The amount and condition of other forest holdings should also be considered. This stand, though diverse, should be handled as one. Some sacrifice must be made in timber production to achieve efficient management.

Immature Stands

A fully stocked immature stand (table 3 and stocking guide, Appendix) requires tending throughout its life. Even before trees become merchantable, weeding and thinning will be needed to concentrate growth on the most desirable trees. Trees likely to be culls, slow

Table 3.—*Stocking guide for maintaining good diameter growth on individual well-situated trees on good sites*[1]

Average d.b.h.[2]	A-level[3]	B-level[4]
	No. of trees	
6	475	202
10	202	112
14	112	71
18	71	49
22	49	36
26	36	27

[1]From Putnam *et al.* 1960.
[2]Average diameter of dominant and codominant trees.
[3]Corresponds to A-level, appendix. Beyond this, stand i overstocked.
[4]Corresponds to B-level, appendix. With fewer trees, site isn't full utilized.

rowers, or of little commercial value (see table 1) hould be removed unless they are needed to help orm the crop trees. If the remaining stand is still too ense, crop trees will need to be removed. The goal is o attain a stand of approximately 50 high quality rees of commercial species per acre at maturity.

Releasing these crop trees through harvest of pole-ized or larger trees of commercial value will yield nerchantable timber. This can result in the cumula-ive yield of 2,000 to 4,000 board feet/acre and 30 to 35 ords of poletimber and topwood from the thinnings efore the final harvest (table 2). The recommended tocking of the stand after each thinning should be ased on the average stand diameter (table 3 and tocking guide, Appendix). Stands with smaller aver-ge diameters should be allowed to grow until they pproximate 80 percent of the fully-stocked level; the ercent should be gradually reduced as stand iameters increase. Thinning at successive lower tocking levels as stands get older will lead to uniform hinning schedules across all stands regardless of age.

The goal is to maintain a relatively uniform density nd diameter distribution throughout the stand as it noves towards maturity. These thinnings through electing individual trees will produce a relatively omogeneous stand.

Jnderstocked Stands

An understocked stand won't fully utilize the site, e., timber production is less than the site's potential. Aore trees are needed to achieve full productivity. 'or young stands with sufficient openings to provide he light needed for intolerant species, planting should e considered. Otherwise clearcut when the stand ecomes merchantable unless deferring the clearcut vould seriously delay bringing the stand to full roductivity.

Establishing a new stand is recommended where nderstocking occurs on otherwise productive sites aving the size and access for timber production.

CONTROLLING STAND ESTABLISHMENT

Within one year of harvesting, bottomland hard-vood sites produce heavy herbaceous vegetation. Jsually, reproduction of desirable trees can come hrough this cover, and after a few years dense apling stands will be established. Occasionally, how-ver, shrubs, cane, and vines get established ahead of ree reproduction and become dense enough to ex-lude trees. For these problem areas you'll have to ontrol this unwanted vegetation, either with herbi-ides or mechanically.

Controlling Composition

Generally, in the areas to be harvested, advanced reproduction will not be present for all species. However, advanced reproduction may be present for green ash, American elm, and various oak species, including pin oak, shingle oak, and swamp white oak. Past management activities and previous uses will determine the inherited composition. Elm-ash-cottonwood is a subclimax type that, without disturbance, will likely convert to oak or to another type.

With clearcutting, disturbance from logging should expose mineral soil and eliminate competing vegetation. If light and soil moisture are sufficient, natural reproduction from seeds can be expected. Stump sprouts are also a source of reproduction for species in the type, particularly green ash, sweetgum, and sycamore. American elm and hackberry also sprout but to a lesser degree. Harvesting during the dormant season will encourage stump sprouting, provide timely seedbed preparation and should be considered whenever practical.

Preferred species in the type are cottonwood, sycamore, silver maple, and green ash. Willow and river birch are acceptable species for forest products. Elm cannot be expected to realize much commercial value due to Dutch elm disease.

Artificial Regeneration

Consider planting within two years after harvesting if adequate natural regeneration is not present. Planting is expensive because it involves site preparation and maintenance. Select sites carefully; avoid locations that are often flooded.

Clear sites of competing vegetation and debris before planting, as follows:

1. Shear all residual woody vegetation at or near ground level,
2. Pile debris in windrows and burn,[3] and
3. Rake entire surface again to collect any vegetation missed under 2. The planting bed should then be deeply disced and tilled.

The species recommended for planting are cottonwood, green ash, and sycamore, preferably from genetically improved stock. Cottonwood is generally established from cuttings. Green ash and sycamore are generally established from seedlings and attain heights and diameters near that of cottonwood.

Plant seedlings 12 by 12 (feet) as early as possible in the spring. Better survival is achieved with an auger than with a dibble bar. For the first 2 or 3 years, mechanical weeding will be necessary.

[3]*Air quality standards may prohibit burning.*

DAMAGING AGENTS

Flooding

Prolonged flooding during the growing season may kill reproduction and reduce the growth of larger trees. If repeated for 2 or 3 consecutive growing seasons, mature trees will die. Of the species in the association, oaks, sweetgum, river birch, sycamore, and elm are most affected by flooding; ash, cottonwood, and willow, the least.

Flooding during the dormant season is not detrimental to the trees and may even benefit the site. Silt deposited during flooding provides seed beds for germinating cottonwood, willow, sycamore, and other light-seeded species.

Fire

Fire should not be used as a management tool for bottomland hardwoods. All species in this type are very susceptible to fire damage; ground fires readily kill saplings and seedlings and wound larger trees. These wounds, acting as points of entry, facilitate the onset of heartwood decay, which leads to substantial cull and volume loss in bottomland hardwoods.

Following fire, vines and weeds originate and flourish on exposed sites where the trees have been killed. Ground fire destroys organic matter, which causes site deterioration.

Disease

Important diseases in elm-ash-cottonwood are Dutch elm disease, (*Levatocystics celuri*) and heartwood decay. Dutch elm disease has killed most mature elms throughout the type; the remaining ones are primarily in the smaller size classes and few are available for products. Effective control measures have not been developed for Dutch elm disease; all merchantable elm should be removed in any harvesting operation.

Heartwood decay, the major cause of defect and volume loss in the type, generally enters the tree through fire wounds or dead branch stubs. From these points of entry, decay spreads and can destroy the tree. Heartwood decay can largely be controlled by appropriate fire protection.

Insects

Many insects attack the elm-ash-cottonwood type. Elm bark beetles, *Scolytus multistriatus* and *Hylugopinus rutipes*, are insect vectors for Dutch elm disease. Canker worms, *Alsophila pometaria* and *Paleacrita vernata*, and the forest tent caterpillar, *Malacosma udisstria*, major defoliators, and the borers, *Plectrodeva scalator* and *Saperda calvacata*, cause losses in tree growth, survival, and quality.

Trees of low vigor receive the most insect damage. Good forest management practices, e.g., removing damaged, suppressed, and slow growing trees, are the best means for controlling potential damage.

OTHER RESOURCE CONSIDERATIONS

Wildlife

Because elm-ash-cottonwood is located along major water courses and frequently bordered by cropland, it is a primary source of habitat for a variety of wildlife. Wood duck and other waterfowl find nesting areas, food, and shelter here. Also found here are important game species—whitetail deer, ruffed grouse, and gray squirrels; fur bearing amimals—raccoons, beavers and muskrats; and predators such as red fox, skunk and others. The type also provides habitat for a variety of songbirds.

Timber harvesting helps provide the diversity of habitat that is desirable for wildlife. Management practices can be modified to meet wildlife requirements. For example, three or four den trees per acre can be left for squirrels and birds. During timber stand improvement, kill some unwanted stems but leave them standing to provide cavities for birds. Leave occasional oak and hickory along with some grapevines, paw paws, and other species, to provide wildlife food.

Water

Elm-ash-cottonwood is important for stream bank stabilization and erosion control. Do not harvest within 50 feet of the stream. Recommended harvests should have little if any effect on water quality or quantity as sites generally will be flat, with slow runoff. Water yields may increase slightly following cutting, but will soon return to normal as reproduction is established. Managers of land along streams should be familiar with riparian rights. Each State has its own laws concerning stream maintenance and control.

Recreation and Esthetics

The elm-ash-cottonwood type has great value for dispersed recreation activities. These activities—including hunting, fishing, nature hiking, and bird

atching—are mostly harmonious with timber management. A well managed forest offers a variety of ee sizes and wildlife habitats that contribute to any recreation activities.

The visual impact of timber harvesting can be educed in several ways. These include leaving islands f standing timber in clearcuts, leaving buffer zones to screen harvesting, having irregularly-shaped harvest zones with only portions visible from one spot, and lopping tops to leave a neat and clean area. Disturbances from logging that expose mineral soil will provide seed beds for natural reproduction; within 3 years, vegetation on the site will obliterate any trace of logging.

APPENDIX

Site Index Curves

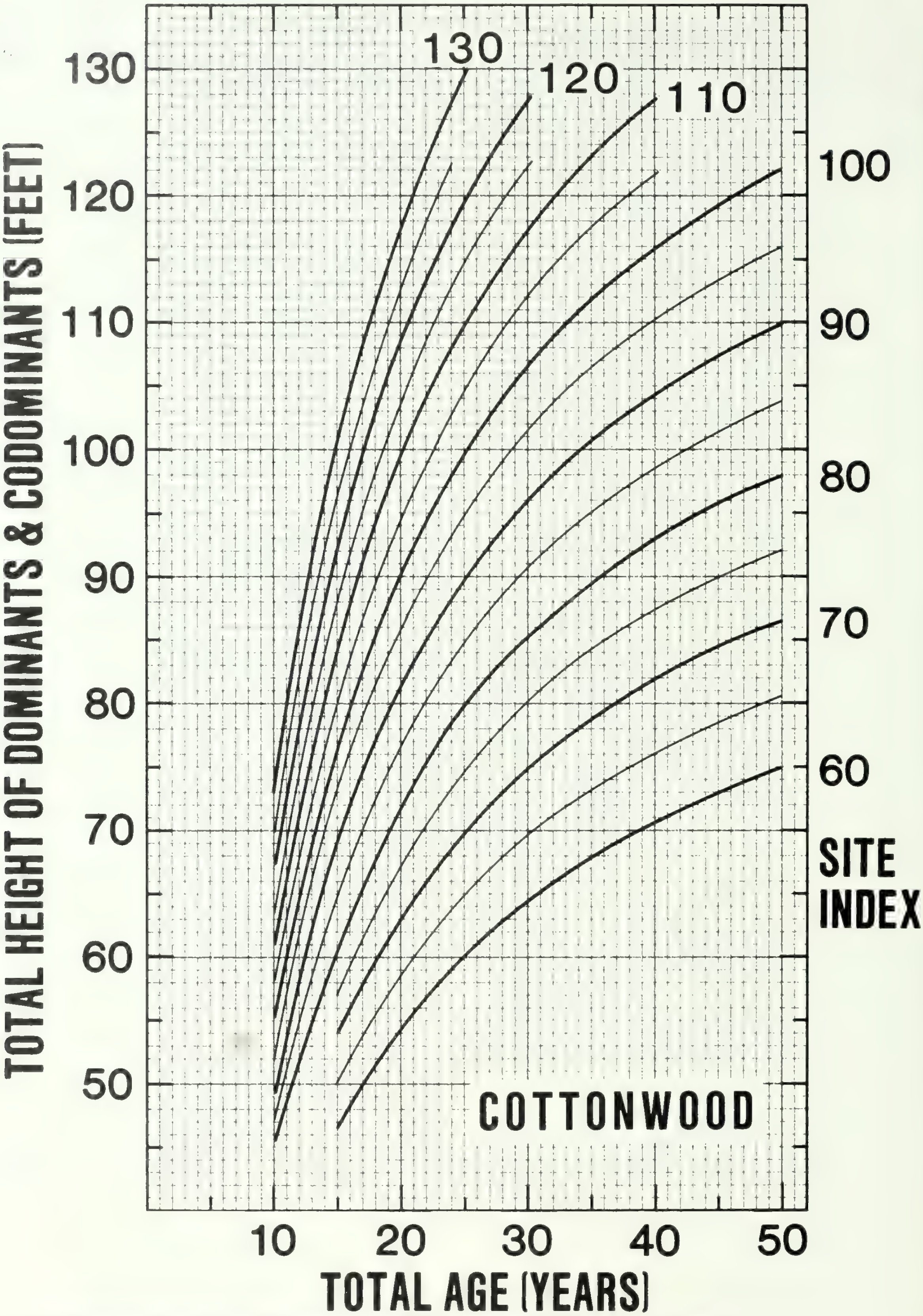

Figure 1.—*Site index curves for eastern cottonwood (Carmean* et al.*) (base age 25 years).*

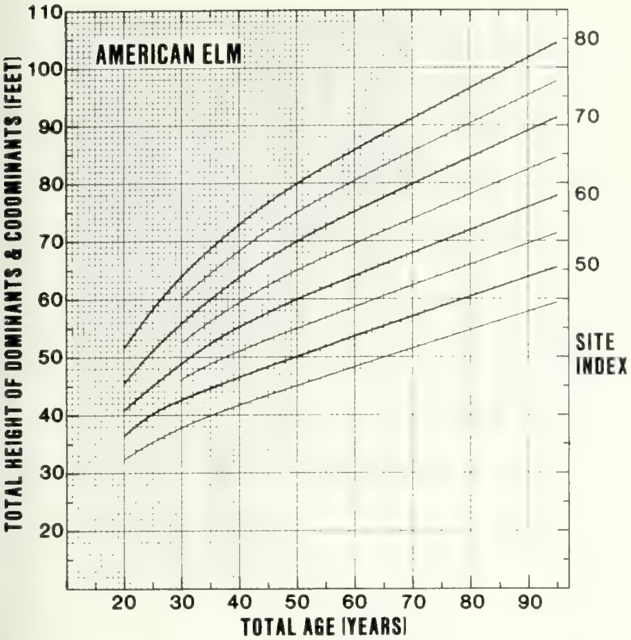

Figure 2.—*Site index curves for American elm (Carmean* et al.*)(base age 50 years).*

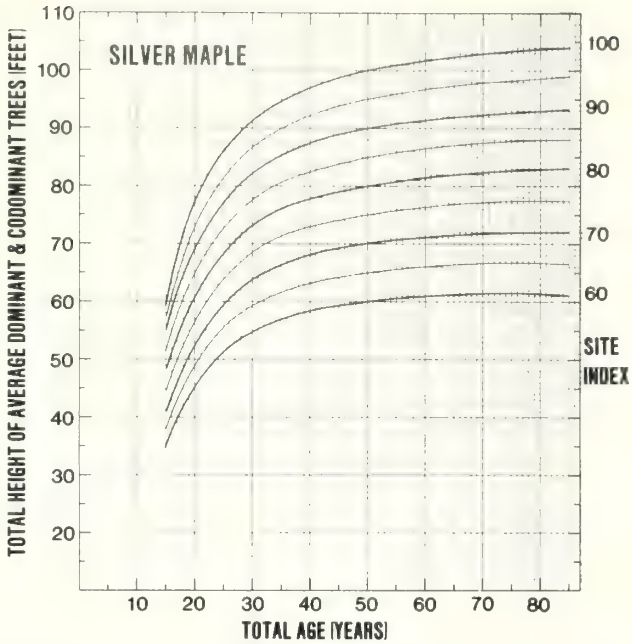

Figure 4.—*Site index curves for silver maple (Carmean* et al.*) (base age 50 years).*

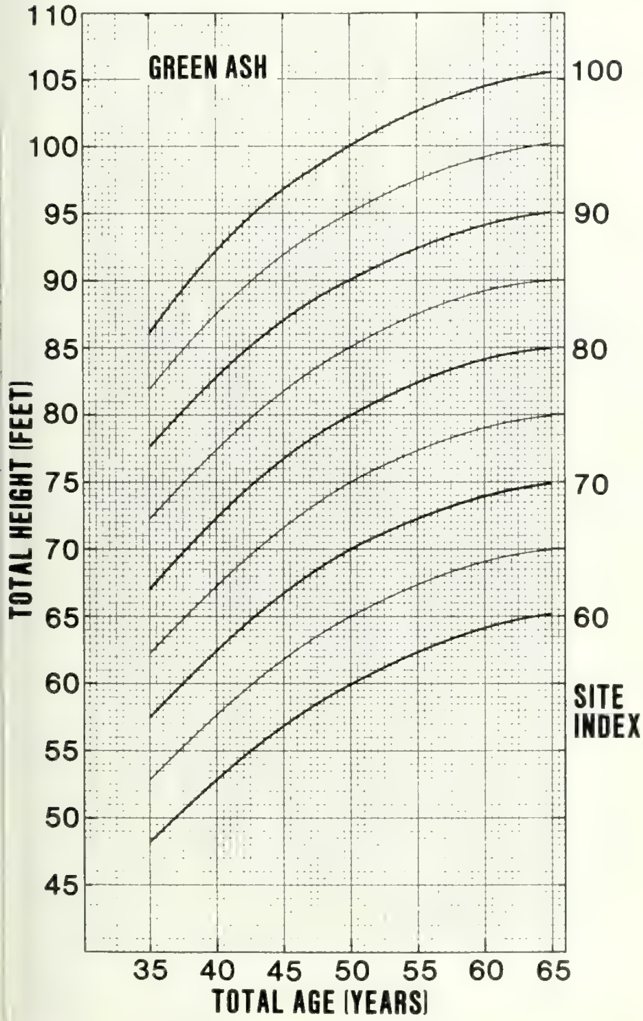

Figure 3.—*Site index curves for green ash (Carmean* et al.*) (base age 50 years).*

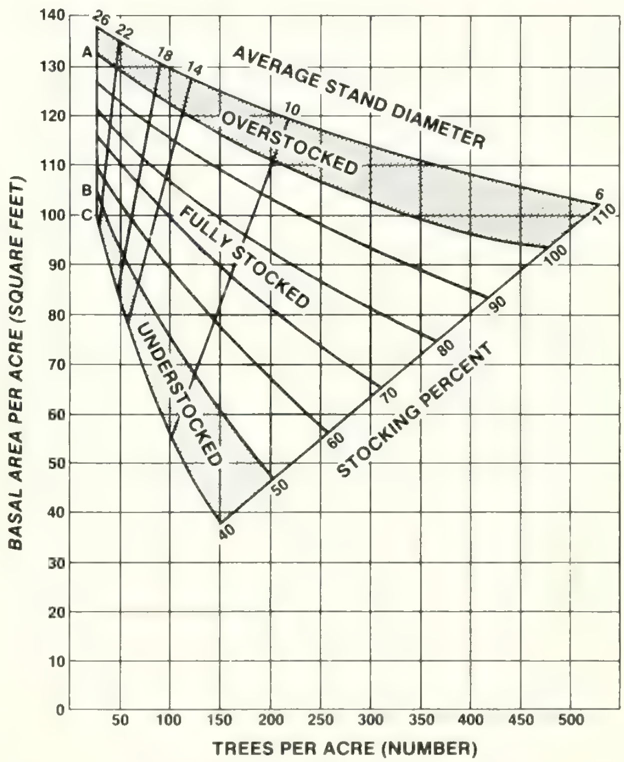

Figure 5.—*Relation of basal area, number of trees, and average tree diameter to stocking percent for elm-ash-cottonwood (based on Putnam* et al. *1960).*

Even-age Stocking Guide

Figure 5 shows the relation of basal area, number of trees, and average stand diameter to stocking percent for elm-ash-cottonwood. The area between curves A and B indicates the range of stocking where trees can fully utilize the site. The curves were developed from Putnam *et al.* 1960.

To use the curves, first inventory the existing stand to determine the number of trees and basal area per acre. Procedures for conducting this inventory are well established but not included here (see Roach 1977). He recommends the use of point sampling to determine basal area per acre and 1/20th-acre plots for number of trees. An example of the use of the graph follows.

Assume a stand contains 100 trees and 130 square feet of basal area per acre. Locating this plot on the graph indicates the stand is over-stocked and has an average tree diameter of 16 inches. From the located point project a line down to the left, parallel to the line of 14 inches average diameter, and note the basal area where the line crosses the B-level stocking.

Deduct B-level stocking (90 square feet) from stand basal area (130 square feet) to arrive at the amount of basal area that can be removed in an intermediate cut (40 square feet). As much as 40 square feet can be removed from the stand without making it under-stocked.

Metric Conversion Factors

To convert	to	Multiply by
Acres	Hectares	0.405
Board feet[4]	Cubic meters	0.005
Board feet/acre[4]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[4]	Cubic meters	2.605
Cords/acre[4]	Cubicmeters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	([5])
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Miles	Kilometers	1.609
Miles/hour	Meters/second	0.447
Number/acre	Number/hectare	2.471
Ounces	Grams	28.350
Ounces/acre	Grams/hectare	70.053
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Pounds/gallon	Kilograms/liter	0.120
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	1.102
Tons/acre	Metric tons/hectare	2.242

[4]*The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.*

[5]*To convert* °F to °C, use the formula: C°= (F°-32)/1.8.

Common and Scientific Names of Plants and Animals

Plants

Ash, green .... *Fraxinus pennsylvanica*
Birch, river .... *Betula nigra*
Cottonwood, eastern .... *Populus deltoides*
Elm, American .... *Ulmus americana*
Grape .... *Vitis* spp.
Hickory .... *Carya* spp.
Maple, silver .... *Acer saccharinum*
Oak, pin .... *Quercus palustris*
Oak, shingle .... *Quercus imbricaria*
Oak, swamp white .... *Quercus bicolor*
Oak, white .... *Quercus alba*
Paw paw .... *Asimina triloba*
Sycamore .... *Platanus occidentalis*
Willow, black .... *Salix nigra*

Animals

Beaver .... *Castor canadensis*
Deer, whitetailed .... *Odocoileus virginianus*
Duck, wood .... *Aix sponsa*
Fox, red .... *Vulpes vulpes*
Grouse, ruffed .... *Bonasa umbellus*
Muskrat .... *Ondatra zibethica*
Racoon .... *Procyon lotor*
Skunk .... *Mephitis* spp.
Squirrel, gray .... *Sciurus carolinensis*

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency consult your county agriculture agent or State extension specialist to be sure the intended use is still registered.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

Myers, Charles C.; Buchman, Roland G.
Managers handbook for elm-ash-cottonwood in the North Central States. Gen. Tech. Rep. NC-98. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 11 p.

Presents the resource manager with a key for choosing silvicultural practices for the elm-ash-cottonwood type in the North Central States. Timber production is emphasized.

KEY WORDS: Forest management, regeneration, management guide, bottom-land hardwoods, timber production.

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-99**

Second Workshop on Seedling Physiology and Growth Problems in Oak Planting

(Abstracts)

U.S. Department of Agriculture, Forest Service
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
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December 1984

SECOND WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTING, MISSISSIPPI STATE UNIVERSITY, FEBRUARY 8-9, 1983 (ABSTRACTS)

Edited by Paul S. Johnson and John D. Hodges

Sponsored by

Department of Forestry

Mississippi State University

North Central Forest Experiment Station

USDA, Forest Service

St. Paul, Minnesota

and

Southern Forest Experiment Station

USDA, Forest Service

New Orleans, Louisiana

PREFACE

On February 8-9, 1983, a group of foresters, forest scientists, and tree physiologists met at Mississippi State University for the Second Workshop on Seedling Physiology and Growth Problems in Oak Planting. The first workshop was held at Columbia, Missouri on November 6-7, 1979. The purpose of the workshop was to provide a forum for exchange of ideas and research results in three subject areas: (1) physiology and genetics, (2) seedling propagation and production methods, and (3) field performance of planted oaks. The last workshop was jointly sponsored by the Department of Forestry, Mississippi State University, the North Central Forest Experiment Station and the Southern Forest Experiment Station, USDA Forest Service. Abstracts of papers given at the workshop are presented here.

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OAK PHYSIOLOGY AND GENETICS

IMPROVING ACORN GERMINATION AND SEEDLING GROWTH THROUGH TREE IMPROVEMENT AND CULTURAL PRACTICES

J. W. Van Sambeek, *Research Plant Physiologist,*
and
George Rink, *Research Geneticist,*
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Carbondale, Illinois

Early vigorous root growth of planted seedlings is critical for good establishment and early height growth in white oak (*Quercus alba* L.) plantations. Indolebutyric acid applied to roots before planting doubled or tripled early root growth of 1-0 seedlings in the greenhouse. However, that treatment failed to improve first-year survival or height growth on a graded mine spoil in southern Illinois. Survival ranged from 35 to 69 percent and new shoot growth from 4 to 12 cm. Only site variation significantly affected both survival and shoot growth.

Little is known about the variation in white oak's ability to survive and grow under environmental stress. Preliminary experiments with 6-week-old white oak seedlings established under factorial combinations of 2 levels of moisture stress (-0.5 and -0.7 bars), with and without fertilizer, and watered with either distilled water or leachate from tall fescue showed no differences in seedling shoot growth after 8 weeks; however, differences among half-sib progeny of 5 local trees were apparent.

Preliminary results of an acorn storage study suggest that short-term storage of acorns in sealed 4-mil plastic bags results in a rapid loss in viability. We are also studying rooting of white oak cuttings under aseptic conditions with various combinations of plant growth regulators and cultural regimes to find ways to vegetatively propagate white oak.

PHYSIOLOGICAL RESPONSES OF CONTAINER-GROWN MYCORRHIZAL BLACK OAK SEEDLINGS TO DROUGHT

David J. Moorhead, *Graduate Research Assistant,*
School of Forestry, Fisheries, and Wildlife,
University of Missouri,
Columbia, Missouri

Growth, water relations, and photosynthesis were monitored during the 1980 growing season in a two-year-old outplanting of black oak (*Quercus velutina* Lam.); seedlings tested were container-grown (noninoculated), container-grown inoculated with *Pisolithus tinctorius* , and 2-0 bare-root stock (noninoculated). Seedling performance was evaluated during three periods: (1) pre-drought, (2) post-drought periods with abundant soil moisture and moderate air temperatures, and (3) a severe midseason drought period with low soil moisture and maximum daily air temperatures greater than 38°C. Despite conditions of low soil moisture and high evaporative demand during much of the growing season, mycorrhizal seedlings grown in containers grew significantly more in height and diameter than 2-0 bare-root seedlings ($P < .05$). Comparison among the three types of seedlings revealed no significant differences in water relations or photosynthesis during pre-drought and post-drought periods. However, during peak drought conditions, the inoculated and noninoculated container-grown seedlings maintained significantly greater rates of leaf conductance and photosynthesis than the 2-0 bare-root seedlings. Bare-root seedlings minimized water loss by reducing leaf conductance and limiting photosynthesis during peak drought. Containerization and mycorrhizal inoculation decreased calculated soil-plant bulk water flow resistance when soil moisture availability was low. This may have resulted from the greater root absorptive surface area of the container-grown seedlings. In addition, mycorrhizal roots may have reduced water flow resistance by further increasing root absorptive area by extension of fungal hyphae into the soil and thus providing a lower resistance for water flow through the root cortex.

REGENERATION AND GROWTH OF BOTTOMLAND HARDWOODS: STUDIES IN PROGRESS

Jim L. Chambers, *Associate Professor,*
School of Forestry and Wildlife Management,
Louisiana State University,
Baton Rouge, Louisiana

Regenerating Bottomland Hardwoods by Underplanting.--Stands in 5 bottomland hardwood types were studied in southeastern Louisiana. Designation of types was based on relative basal area and relative density of tree species. Types studied included: Sugarberry-Sweetgum-Boxelder, Red Maple-Swamp Tupelo-Green Ash, Sweetgum-American Hornbeam, American Beech-Swamp Tupelo-Spruce Pine, and Swamp Tupelo-Sweetbay. Within each type, ten 0.2-ha plots were established over a range of basal areas from 19.8 to 46.2 m^2 per ha. In all plots, trees and shrubs less than 10 cm dbh were severed near ground line. Five plots from each type were not further thinned. The remaining five plots in each type were further thinned by removing 12, 24, 36, 48 or 60 percent of the remaining plot basal area. One-year old seedlings of *Quercus nigra* L., *Q. michauxii* Nutt., *Q. nuttallii* Palmer, *Fraxinus pennsylvanica* Marsh., *Liquidambar styraciflua* L., and *Taxodium distichum* L. were underplanted at 4.57 x 4.57 m spacing on the interior 0.1 ha of each thinned plot and 1 unthinned plot in each type. Changes in understory light intensity, crown coverage, seedling survival, seedling height and diameter growth, and growth of competing trees will be measured annually to determine the feasibility of underplanting for regenerating bottomland hardwoods that have little desirable natural regeneration.

Effect of Shading on Seedling Growth and Survival.--One-year-old seedlings of *Q. falcata* var. *pagodifolia* Ell., *Q. nigra* L., *Q. nutallii* Palmer, *F. pennsylvanica* Marsh. and *L. styraciflua* L. were transplanted to nursery beds. Zero, 63, and 73 percent shade were applied by covering or not covering the plots with neutral density black woven shade cloth. Forty seedlings of each species were included in each plot and all treatments were replicated three times within the nursery. The effects of shading on seedling survival and growth will be monitored for two years.

Effects of Environmental Factors on Seedling Growth.--We are also studying optimum conditions and limits of seedling tolerance in controlled environments. Species include *Q. falcata* var. *pagodifolia* Ell., *Q. nuttallii* Palmer, *F. pennsylvanica* Marsh., and *L. styraciflua* L. We are varying air temperature, relative humidity, light intensity, and soil moisture over a range of conditions common to seedlings in their natural environments. Under these conditions, photosynthesis, stomatal conductance, components of plant water potential, and transpiration are monitored at each stage of growth. This study will provide information about conditions necessary for survival and growth of seedlings.

ECOLOGICAL FACTORS, MORPHOLOGICAL CHARACTERISTICS, AND PHYSIOLOGICAL PROCESSES AFFECTING ESTABLISHMENT AND GROWTH OF NORTHERN RED OAK--A NEW RESEARCH PROGRAM

J. G. Isebrands, *Tree Physiologist,*
and
T. R. Crow, *Project Leader,*
USDA Forest Service,
North Central Forest Experiment Station,
Rhinelander, Wisconsin

We recently initiated a research program to determine the biological and environmental factors that influence establishment and growth of northern red oak (*Quercus rubra* L.). Ecological factors, morphological characteristics, and physiological processes affecting establishment will be studied. Our premise is that if the mechanisms of the processes regulating oak seedling growth are more clearly understood, silviculturists and geneticists will be able to use this knowledge to increase growth through improved cultural practices and varieties.

An integrated approach will be used in the physiological experiments. This approach includes collecting data on crown morphology, photosynthesis, respiration, photosynthate distribution, and growth analysis for the same or morphologically comparable trees. Initial experiments will be conducted on plants grown in controlled environments (e.g., growth room, greenhouse, and biotron). Emphasis will be on physiological aspects of leaf aging and recurrent flushing in oak seedlings. The potential of using plant growth regulators to stimulate early growth will also be investigated. Hypotheses resulting from these studies will be tested in subsequent field experiments.

Vegetative propagation of oak will also be studied and resultant techniques will have application to silviculture and genetics. With vegetatively propagated plants it will be easier to determine plant responses to multiple environmental factors than in plants raised from seed because of reduced variation among plants.

Primary objectives of the ecological research will be to better define the reproductive strategies of northern red oak and the conditions that permit the establishment, growth, and development of advance reproduction. The critical factor in regenerating oak is not in the ability of seedlings to survive for a year or two, but in the ability of regeneration to reach a size that can grow rapidly after final harvest cutting. The role of disturbances (especially fire) in reproducing oak will also be studied. The ecological research will be designed to complement the physiological studies.

WHITE OAK ARTIFICIAL REGENERATION IN INDIANA

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Indiana Department of Natural Resources,
Division of Forestry,
Vallonia, Indiana

The Indiana Department of Natural Resources, Division of Forestry, in cooperation with the U.S. Forest Service, recently initiated studies in artificially regenerating white oak (*Quercus alba* L.). Studies include determination of variation in annual seed production and growth of white oak seedlings in plantations. To study seed production, a 5-acre stand located on a state forest in southeastern Indiana was designated as a seed production area. The 150 trees in this stand will be treated with systemic insecticides and fertilized to test treatment effects on seed production and quality. Growth of white oaks in plantations will be studied in relation to nursery culture. Two short-term studies were established to determine the best combination of seedling age, seedbed density, seedbed fertilization, and method of seedling storage for maximizing survival and growth of outplanted seedlings. Effects of the mycorrhizal fungus *Thelephora terrestris* on seedling survival and growth will also be studied. In addition, a limited range, combined provenance/progeny test for white oak will be established at 5 locations in Indiana in 1983. A total of 90 Indiana open-pollinated families, plus families from other states in the Midwest will be included. These test plantations will identify the best seed sources for use in northern and southern Indiana and will later be converted to seed orchards.

ALLELOPATHIC EFFECTS OF GOLDENROD ON OAK SEEDLINGS

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and
Ohio Agricultural Research and Development Center,
Wooster, Ohio

Goldenrod (*Solidago* spp.) is a perennial weed that often forms dense stands in old-fields and open areas in Ohio. These areas are resistant to invasion by oak and other hardwoods. Previous studies have shown that tall goldenrod (*S. altissima*) contains compounds toxic to black locust (*Robinia pseudoacacia* L.) and red maple (*Acer rubrum* L.) seedlings.

In preliminary tests to determine whether tall goldenrod foliage contained compounds allelopathic to oak seedlings, we added various amounts of air-dried, mature goldenrod shoots to soil media of 1-0 northern red oak (*Quercus rubra* L.) nursery stock. Adding 4 grams of litter to 1-quart containers reduced both root regeneration and leaf weight by one-third, and 8 grams reduced growth to less than half that of control trees after one month.

A mung bean rooting assay was used to test for inhibitory compounds in water extracts of leaves, stems, flowers and roots. Results indicated that only leaves of goldenrod contained significant amounts of rooting inhibitor. In a direct test using white oak (*Q. alba* L.) seedlings, water extracts of leaves, stems, flowers and roots were applied to 6-day-old plants growing in slanted glass tubes where root growth could be observed. As with mung beans, only water extracts of leaves were strongly inhibitory; taproot elongation rates were reduced 30 percent three days after the initial watering. Although inhibition of nutrient uptake is a commonly reported allelopathic effect, the rapid reduction of root elongation observed suggests that the allelochems affected physiological processes directly related to extension growth.

Goldenrod foliage was collected in July, September, and November and tested for seasonal differences in inhibitor levels. The results indicated that by November goldenrod leaves contain little if any inhibitors.

In addition, soil from cleared (goldenrod removed) and uncleared plots in a goldenrod stand was also collected at different seasons and stored. The cleared plots remained nearly barren of new weed plants except in the shallow pits where soil samples were removed. Here, numerous weed seedlings appeared in the fall. Inhibitor levels of the seasonally collected soil samples will be determined in the spring of 1983.

GENETIC COMPETITION STUDY FOR WATER OAK

Samuel B. Land, Jr., *Associate Professor, Department of Forestry, Mississippi State University, Mississippi State, Mississippi*

A study to evaluate intergenotypic competition among open-pollinated families of water oak (*Quercus nigra* L.) was established in March 1978 in northeastern Mississippi. One-year-old nursery seedlings from eight mother trees (three from eastern Mississippi and five from western Mississippi) were planted in a Nelder's Wheel design. Trees along a spoke in the wheel design were planted at spacings approximating the following:

(1) Interior border,
(2) 8 feet x 8 feet,
(3) 9.3 feet x 9.3 feet,
(4) 11 feet x 11 feet,
(5) 12.8 feet x 12.8 feet, and
(6) Exterior border.

The same family was used for all six positions on a spoke. Families were assigned to adjacent spokes in a particular order to provide competition among trees of only a single family (pure stands) and competition among trees of different families (mixed stands).

After five growing seasons in the field, survival was 99.2% and height averaged 12.7 feet. Crown closure had occurred only for the largest trees at the closest spacings. The effects of stand density and intergenotypic competition were not yet apparent.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

CORRELATING ACORN QUALITY WITH SEEDLING QUALITY

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Starkville, Mississippi

The objective of this research was to evaluate tetrazolium (TZ) staining and several germination response variables as indicators of seed vigor in southern oaks. Multiple lots of white oak (*Quercus alba* L.) and cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) were used to relate seed vigor tests to seedling growth in nursery beds. In general, seed tests could not predict oak seedling growth. Two seed tests, TZ stain percent and peak value (PV) (a measure of germination rate) were significantly correlated with nursery germination of cherrybark oak. However, there were no significant correlations for white oak. TZ stain percent was significantly correlated with germination capacity in lab tests on both species. We thus recommend using a measure of germination rate such as PV or mean germination time for evaluating relative quality of acorns. However, TZ staining is an acceptable method for testing cherrybark oak.

OAK REGENERATION RESEARCH IN INDIANA

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Oak regeneration research by the North Central Forest Experiment Station is just getting under way in Indiana. We have recently established a study in natural regeneration to determine the effects of three overstory density treatments (40, 50, and 60 percent stocking) and three understory treatments (check, cut all except oak, and cut all more than 2 meters tall except oak). A fourth understory treatment uses prescribed burning in the 50 percent stocking density.

Other studies initiated include determining: (1) effects of undercutting in the nursery bed on root fibrosity and subsequent growth of outplanted northern red (*Quercus rubra* L.) and white oak (*Q. alba* L.) seedlings; (2) how to increase white oak acorn production by fertilization and systemic insecticides; (3) how to increase growth of planted red, white, and black (*Q. velutina* Lam.) oaks by interplanting with nitrogen-fixing shrub and tree species; and (4) when to collect and how to handle white oak seed for optimum germination and seedling production.

Results from the germination study (4) above showed that seed stored in 4-mil plastic bags lost viability rapidly with increased storage time. But seed stored in 1.75-mil plastic bags and cloth bags did not lose viability with increased storage time. Apparently, the 4-mil bags did not permit adequate gas exchange. Thus, if 4-mil bags are used they should be perforated or kept partially open.

INITIAL ISOLATES OF INSECT AND FUNGAL PREDATORS FROM QUERCUS ACORNS

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Southern Forest Experiment Station,
Starkville, Mississippi

Freshly collected acorns of white oak (*Q. alba* L.), cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.), water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.) all contained acorn weevils (*Curculio*). In addition, *Milissopus latiferreanus* (LEPIDOPTERA: Tortricidae) was isolated from cherrybark oak and water oak. The pericarp of water oak was excessively cracked and also contained *Ephestia* (LEPIDOPTERA: Pyralididae). Undertermined species of *Valentinia* (LEPIDOPTERA: Blastobasidae) emerged in large numbers from all species of acorns observed here.

Two fungal spores observed with lactophenol blue from sectioned gut of *Curculio* resembled *Fusarium* but were not identified. No *Fusarium* spores were observed from *Curculio* gut smear on slides. PDA isolates were recovered from head, gut, and carcass of *Curculio* larvae. *Pennicillium* was isolated from head and carcass portions, while an undetermined white, sterile mycelia was isolated from head, gut, carcass, and the whole larvae. Additionally, *Fusarium solani* and *Epicoccum purpurascens* were isolated from acorns of white oak and water oak.

Although these isolations are believed to be from acorn surface contaminants, it should be noted that acorn pericarps were cracked. These cracks may have allowed internal cotyledon contaminants to have grown on the agar medium. However, the cracks are quite common on both freshly collected as well as stored acorns. If a separate group of organisms is specific for the pericarp surface, as opposed to the cotyledon-embryo tissues, they would have potential infection capability through these commonly occurring, natural fissures in the pericarp. It is also possible that symbiotic or beneficial associations between seed germination and seed contamination occur.

Additional studies are appropriate to determine the functional role of each of these isolated predators. After this initial screening to determine contaminants, pure culture inoculations onto surface-sterilized seed are in order to observe fungal effects on acorn germination.

ECTOMYCORRHIZAL FUNGUS INOCULATION IMPROVES QUALITY OF OAK SEEDLINGS USED FOR ARTIFICIAL REGENERATION

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Southeastern Forest Experiment Station,
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In experimental plantings, most oak seedlings planted by conventional techniques survive but growth for 2 to 3 years after planting is usually slow. During this period, dense competing vegetation supresses oak seedling growth. Poor ectomycorrhizal development on planting stock may account for some of this slow initial growth.

At the Institute for Mycorrhizal Research and Development, we have increased survival and growth of pine seedlings on various sites by inoculating nursery beds and container growing medium with the ectomycorrhizal fungus *Pisolithus tinctorius*. We are now attempting to learn if similar treatments with that and other symbionts will benefit oak seedlings.

Initial studies have shown that inoculation procedures developed for pines are easily adapted to bare-root and container-grown northern red (*Quercus rubra* L.), white (*Q. alba* L.), black (*Q. velutina* Lam.), bur (*Q. macrocarpa* Michx.), pin (*Q. palustris* Muenchh.), and sawtooth (*Q. acutissima* Carruthers) oaks. From this study we should learn when bare-root seedlings will commence and how long they will sustain height growth when roots are colonized by ectomycorrhizal fungi before planting. We are also investigating using mycorrhizal container-grown oak seedlings for selected planting sites. Using properly grown container stock with suitable ectomycorrhizal development may avoid many problems encountered with bare-root seedlings. Root pruning is not required with container stock and all roots and ectomycorrhizae developed in the container are retained and remain intact at planting. Storage generally is not a problem because container stock is held in the greenhouse or lath house until conditions are appropriate for planting. The planting operation is easier because of the uniformity among seedling root systems.

We plan to solve the problem of slow early seedling growth of planted oaks by developing planting stock, both bare-root and container-grown, with appropriate ectomycorrhizal fungi and root morphology that are better adapted for outplanting.

MYCORRHIZAE AND THE ARTIFICIAL REGENERATION POTENTIAL OF OAK

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Container-grown and bare-root black oak (*Quercus velutina* Lam.) seedlings inoculated with *Pisolithus tinctorius* were grown for one season in 750 cc Spencer-Lemaire containers in the greenhouse or in a nursery, respectively; noninoculated seedlings were also grown in containers and in the nursery for comparison. Examination of seedlings before planting revealed that 38 and 45 percent of the roots of the container-grown and 1-0 bare-rooted seedlings, respectively, were infected with *Pisolithus.* Bare-root seedlings were significantly larger than container-grown seedlings. However, total root system length of the container-grown seedlings was significantly greater.

Three years after outplanting on two Missouri Ozark clearcut sites, survival of the container-grown seedlings inoculated with *Pisolithus* was significantly greater than the inoculated and noninoculated bare-root stock. Root weight, shoot length and weight, and leaf area of the inoculated container-grown seedlings increased significantly during the first three years in the field. The inoculated and noninoculated bare-root stock suffered from repeated shoot dieback and leaf area remained relatively small. Percent infection with *Pisolithus* on roots of the container-grown stock was 25 percent after three years. Mycorrhizal infection of the bare-root stock declined to less than 15 percent during the same period. Total root system length and yearly increments of new root growth were significantly greater for container-grown stock inoculated with *Pisolithus* than for other seedlings.

Seasonal evaluation of seedling xylem pressure potential, leaf conductance, and microenvironment indicated that container-grown stock inoculated with *Pisolithus* better avoided water stress during droughts than noninoculated seedlings. Soil-plant liquid flow resistance was significantly lower in the *Pisolithus* inoculated seedlings than the noninoculated stock.

Preliminary greenhouse and field screening trials with five other species of mycorrhizal fungi with black, white (*Q. alba* L.), and English oak (*Q. robur* L.) indicate an expanded potential for the use of mycorrhizae technology in artificial regeneration.

Oak Seedling Propagation and Production Methods

METHODS FOR PRODUCTION OF OAK SEEDLINGS

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and
William W. Elam, *Associate Professor,*
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After five growing seasons in the field, the best container system produced seedlings that were taller and larger than bare-root seedlings of the same age even though the bare-root seedlings were larger at the end of the first season. This was true for Nuttall oak (*Quercus nuttallii* Palmer), Shumard (*Q. shumardii* Buckl.), cherrybark (*Q. falcata* var. *pagodifolia* Ell.), and water (*Q. nigra* L.) oaks.

Results of nursery studies, using the same four species showed that seedlings of acceptable size can be grown in one season if density of seedlings in the nursery bed is about 8 seedlings per square foot and sowing is done with stratified seed by early April. A density of 8 seedlings per square foot yielded more plantable seedlings than lower densities and as many as at higher densities; however, the largest seedlings occurred at a density of 8 per square foot. If sowing is done after mid-April, seedlings will not be of plantable size at any density.

Methods for modifying the root system of hardwood seedlings in nursery beds are being studied in cooperation with International Paper Company. Methods include: (1) early undercutting (taproot pruned), (2) late undercutting, (3) lateral root pruning, and (4) early undercutting plus lateral root pruning. In addition, one-half of all treatment plots were inoculated with mycorrhizae. Cherrybark oak, green ash (*Fraxinus pennsylvanica* Marsh.), and sweetgum (*Liquidambar styraciflua* L.) were used in the study. Early results indicate that the treatments, particularly treatment 4, may improve growth of outplanted seedlings.

FIELD PERFORMANCE OF PLANTED OAKS

SURVIVAL AND HEIGHT OF BLACK OAK PLANTED IN EIGHT LOCATIONS

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Planted oaks usually survive but grow poorly on upland sites in the South. This general observation was reinforced by the survival and growth of black oak (*Quercus velutina* Lam.) planted from 1967 to 1971 in the Cumberland Plateau and Highland Rim Region.

Seedlings from a Tennessee Valley Authority nursery were planted at a 7- x 7-foot spacing on 8 sites within four landtypes. Site quality ranged from poor to moderately good. Each site supported mixed hardwood stands prior to outplanting. The hardwoods were felled and individual stems injected with herbicide.

When the seedlings were 6 to 8 years old, three weeding intensities and a control were imposed: (1) a single weeding, (2) an annual weeding, and (3) a weeding every two years. Weeding consisted of cutting all vegetation within 2 feet of the planted oak and injecting all non-planted hardwoods on the plot.

Survival of the oaks over the study averaged 75 percent when weeding treatments were initiated. Survival of trees present at the time of weeding ranged from 57 to 100 percent. Heights of the 11- to 14-year-old oaks averaged 1.7 to 8.5 feet. There were no consistent effects of the cleaning treatments on height growth. In fact, at three locations height of unweeded oaks surpassed the height of weeded oaks.

As part of another study, yellow-poplar (*Liriodendron tulipifera* L.) was planted near the oaks. Heights of these yellow-poplars showed that site quality ranged from poor to moderately good.

These results indicate that black oak should not be planted on a broad scale in the uplands.

Field Performance of Planted Oaks

EXPERIENCES AT THE SOUTHERN HARDWOOD LABORATORY ON GROWING OAKS IN PLANTATIONS AND NURSERY

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Southern Forest Experiment Station,
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Planting studies at the Southern Hardwoods Laboratory tested Nuttall oak (*Quercus nuttallii* Palmer), water oak (*Q. nigra* L.), and cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) under three levels of cultural intensity: disking, mowing, and no treatment (control).

Height and diameter growth were 2½ times greater in disked plots than in mowed or control plots and survival was increased by 30 to 40 percent. However, one study showed that these oaks cannot survive on soils with a pH exceeding 8.0.

Leaves of trees in disked plots had significantly higher N concentrations than trees in other plots. Foliar nutrient concentrations of P, K, Ca, and Mg were not affected by cultural treatment. However, if we assume that leaf weight is related to D^2 or D^2H, then from 3 to 12 times more of each nutrient accumulated in trees in disked plots than those in other treatments.

Moisture measurements indicated that trees in disked plots utilized available soil moisture that was used by weeds and grasses in other plots. This could mean up to 50 percent more available moisture for use by trees in disked plots.

Recently, research was initiated on growing large seedlings in the nursery and in large containers for outplanting. No problems have been encountered in growing oaks in the nursery, and outplantings of two-year-old seedlings up to seven feet tall look promising. If a relatively large planted seedling could effectively supplement natural regeneration by increasing the oak component in a stand, it would eliminate the need for expensive site preparation and cultural treatments.

RESPONSES OF PLANTED NORTHERN RED OAK TO THREE OVERSTORY TREATMENTS

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North Central Forest Experiment Station,
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Northern red oak (*Quercus rubra* L.) were planted in upland oak forests of the Missouri Ozarks. The 2,304 planted trees consisted of four classes of nursery stock: small 1+0, large 1+0, 1+1 and container-grown. Shoots were clipped on half of the trees in each class. Plantings were made in 8 clearcut plots and in 16 plots thinned to 60 percent stocking. Stumps of overstory trees (trees 4 cm dbh and larger) removed in clearcutting and thinning were treated with a herbicide to prevent sprouting; similarly, all woody stems from 1.3 to 3.9 cm dbh were cut and treated.

After three field growing seasons, the overstory was removed on one-half of the underplanted plots. After five field growing seasons, average survival was 84 percent. Average heights of survivors were: 118 cm for trees planted directly into clearcuts, 97 cm for underplanted/released trees, and 59 cm for underplanted/unreleased trees. Planted oaks that averaged 30 to 40 cm in net height growth per year after complete overstory removal were at least codominant with the briars (*Rubus* spp.) which formed a closed canopy about 1.5 m tall on the clearcut plots after 5 years.

Based on net shoot growth of trees after overstory removal, success probabilities were estimated using logistic regression analysis. Success probabilities were based on net annual height growth of planted trees after complete overstory removal (i.e., 5 years growth for trees planted directly into clearcuts and 2 years growth for underplanted/released trees). Among all classes of stock and overstory treatments, estimated success probabilities were greater for clipped than unclipped stock. The most successful trees were clipped 1+1 stock with initial shoot diameters (2 cm above the root collar) of 10 mm or more that were underplanted and subsequently released. For clipped 1+1 stock, success probabilities for a success criterion of 30 cm net height growth per year after overstory removal ranged from .61 to .77 for 10 to 16 mm diameter trees, respectively; for a success criterion of 40 cm, success probabilities were .42 to .63, respectively. Success probabilities for the same nursery stock planted directly into clearcuts ranged from .31 to .49 and .12 to .24 for 30 and 40 cm success criteria, respectively. Success probabilities for underplanted/released 1+0 stock 10 to 16 mm in diameter with clipped shoots ranged from .47 to .64 and .26 to .44 for 30 and 40 cm success criteria, respectively. Among trees planted directly into clearcuts, success probabilities were greater for container-grown stock than for any class of bare-root stock for a given initial shoot diameter.

OAK SEEDING AND PLANTING EXPERIENCES

E. C. Burkhardt, *Consulting Forester, Vicksburg, Mississippi*

Twenty-two years of experiences in artificially establishing cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) and Shumard oak (*Q. shumardii* Buckl.) on loess bluff soils near Vicksburg, Mississippi have shown:

A. Initial development is slow.

B. On cleared forest sites four methods can be used: (1) planting large 1-0 seedlings, (2) planting five-month-old to one-year-old container-grown stock, (3) direct seeding, and (4) planting two- to three-year-old nursery stock.

C. On old fields, large 1-0 stock can be planted with success and it is possible that the other methods listed above will work.

D. Each establishment method has its advantages and disadvantages and it is likely that all the methods will be used with success in the future.

E. Competition varies among sites of equal quality but in general competition is more severe on the better sites.

The oldest of these plantings now have dominant cherrybark oaks in excess of 8 inches dbh. This uncultivated old field was planted to 1-0 nursery stock 22 years ago and appeared to be a complete failure for the first five years. Similar results were experienced using the other methods without cultivation.

ESTABLISHMENT OF NUTTALL OAK ON DIFFICULT SITES

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International Paper Company,
Natchez, Mississippi

Two sites that are subject to flooding were planted to Nuttall oak (*Quercus nuttallii* Palmer) prior to the 1981 growing season. Both sites were on heavy clay soils in the Mississippi River floodplain in Mississippi. Flooding occurs annually at site A and once every two to three years at site B. Nuttall oak seedlings grown in 8-cubic-inch Styroblock containers were planted on both sites. Acorns were also direct-seeded on site A, and bare-root seedlings were planted on site B.

First-year survival of container-grown Nuttall oak seedlings was 66 and 20 percent on sites A and B, respectively. Both sites were planted in early June after floodwaters had receded. At the time of planting, site B soils were quite dry. Growth was poor at both sites, probably because of dry soils and hot weather. Rainfall was 80 percent of average in the study areas during the 1981 growing season.

Acorns were direct-seeded on site A in 1981 after the first spring flood which lasted 31 days. Ninety percent of acorns germinated and had grown approximately 8 inches in height when a second 21-day flood occurred. All seedlings originating from the direct seeding were killed by this flood.

In 1982, 1-0 bare-root Nuttall oak seedlings were planted in mid-May at site B. With growing season rainfall during 1982 at 124 percent of average, survival was 88 percent and trees maintained good vigor throughout the first year.

OAK PLANTATIONS: AN INDUSTRY SUCCESS STORY

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Thousands of acres of operationally established hardwoods are being tended by forest industries across the Southeast, and more acreage is being designated for future plantations. Approximately 2,000 acres of the water-willow oak complex (*Quercus phellos* L., *Q. nigra* L., *Q. laurifolia* Michx.) have been planted over the past decade in the Southeast. Technologies have rapidly developed for site preparation, spacing, fertilization, cultivation, chemical weed control, and coppicing methods. Simultaneously, a tree improvement program has begun to select and screen superior phenotypes.

To date the cooperators of the North Carolina Hardwood Research Program have identified approximately 30 superior trees and maintain tests containing 31 water-willow oak families, 7 replicated fertilization trials, 3 seedling seed orchards, 11 growth and yield plots, and have established over 100 species-site trials of which oak was usually a component.

Experience has shown that water-willow oak seedlings should have a 3/8-inch or larger diameter at the root collar and should be in good physiological condition when planted. Planting has been confined to the more clayey soils of the Coastal Plain that have limited internal drainage and a fairly high water table. Successful establishment only occurs following intensive site preparation and regular control of competing vegetation. Depending on soil test results, phosphorus may need to be applied at planting, but nitrogen usually will provide a significant response when applied a few years into the rotation. Another application of fertilizer may be necessary halfway through the rotation. Research is continuing to improve competition control and nursery stock management, and to determine nutritional and site requirements.

THE INFLUENCE OF SITE PREPARATION METHODS ON OAK REGENERATION IN BOTTOMLAND STANDS

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and
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An evaluation of first year natural regeneration of East Texas bottomland hardwoods was conducted on three ten-acre clearcuts. The study evaluated the influences of the following site preparation treatments: shear, shear and broadcast burn, total injection (stems > 4.5 ft. height), partial injection (stems > 3.0 in. diameter), and control (no site preparation). Data were collected from a pre-harvest inventory and from a final inventory after the first growing season. Inventory of the pre-harvest overstory layer showed that bottomland oak species dominated the stands. Oaks comprised 54 percent of the mean total of 70 ft^2 of basal area per acre. The pre-harvest inventory of regeneration revealed that oaks comprised 813 stems per acre of the mean total of 2,787 stems per acre. The final inventory of the regeneration revealed that oaks comprised 560 stems per acre. This decrease was significant ($p < 0.10$) and resulted from a significant decrease in oak regeneration in one ten-acre stand. The other stands remained at or above pre-harvest levels. Oak species composition changed, as cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) decreased from 193 stems per acre before harvest to 14 stems per acre after the first year. Overcup oak (*Q. lyrata* Walt.) regeneration increased from 60 stems per acre before harvest to 140 stems per acre after the first year and thus replaced cherrybark oak as a major regeneration constituent. Comparison between the pre-harvest and the first-year oak regeneration inventories showed that oaks declined as site preparation intensity increased. Control areas showed a 24 percent increase in oaks while shear and burn areas showed a 65 percent decrease. Sprouting was also inhibited by the more intensive site preparation treatments. This study suggests that to facilitate oak development after clearcutting, only low-intensity treatments or no site preparation should be used on bottomland sites.

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INFLUENCE OF SITE AND MYCORRHIZAE ON THE ESTABLISHMENT OF BARE-ROOT AND CONTAINER-GROWN RED OAK SEEDLINGS

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Site condition plays a major role in determining the survival and growth of planted oak seedlings. However, seedling production and planting techniques that minimize planting shock or ameliorate the planting micro-site can reduce negative site effects. The objective of this study was to determine the influence of seedling production method (bare-root or container-grown) and the presence or absence of mycorrhizal endophyte (*Pisolithus tinctorius* (Pt)) on the establishment of 1-0 northern red oak (*Quercus rubra* L.) seedlings planted on sites typically available for reforestation in the Midwest. Sites selected for study were an abandoned old field (AOF), a clearcut (C), and a recently cultivated field (RCF) on marginal farmland.

Three years after planting, seedling survival was greatest on the AOF site (94 percent) followed by sites C (89 percent) and RCF (82 percent). Conversely, 3-year volume growth was greatest on the RCF site (142 cm^3) followed by sites C (78 cm^3) and AOF (67 cm^3). Survival and 3-year volume growth of inoculated and noninoculated container-grown and inoculated bare-root seedlings was significantly greater than noninoculated bare-root seedlings. Foliar N concentration was not significantly influenced by any of the variables tested but tended to be greatest for container-grown seedlings; however, N decreased with time among all classes of seedlings. For a given site, inoculated seedlings had greater concentrations of foliar P than noninoculated seedlings. The persistence of Pt on inoculated seedlings varied depending on site and seedling production method. After 3 years, inoculated seedlings planted on the RCF site had more Pt than noninoculated seedlings. On all sites the correlation (r) between Pt infected roots and annual volume increment or percent foliar P declined with time. Mycorrhizal infection potential of the soil was adequate on the clearcut and old field sites at the initiation of the study and showed little change with time. The RCF site, which initially had low mycorrhizal infection potential, showed large increases in infection potential with time.

U.S. Department of Agriculture, Forest Service. Johnson, Paul S.; Hodges, John D., eds. In: Abstracts, 2d workshop on seedling physiology and growth problems in oak planting; 1983 February 8-9; Mississippi State, MS. Gen. Tech. Rep. NC-99. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 21 p.

Research results and ongoing research activities in oak planting and related physiology and genetics studies are described in 21 abstracts.

KEY WORDS: Plantations, propagation, regeneration.

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North Central Forest Experiment Station

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M. Dean Knighton

PREFACE

In 1974, a multi-disciplined research program on wildlife water-impoundments was implemented by the North Central Forest Experiment Station, U.S. Forest Service. The research was prompted by an aggressive impoundment development effort on the Chippewa National Forest and a need to refine our knowledge of the best management practices for maximizing wildlife benefits and identifying adverse environmental effects. In the latter case, we were most concerned about the effects on the quality of downstream waters. In preparing a problem analysis and in conducting the research, it became apparent that a diverse array of impoundments were common throughout the western Great Lakes region and that various federal and State agencies, counties and private organizations were actively involved in building and managing them for wildlife. The need for a regional workshop focusing on impoundments was obvious. Therefore, we scheduled a workshop to coincide with the conclusion of the North Central Forest Experiment Station's impoundment research program. The workshop, sponsored by the North Central Forest Experiment Station and the Chippewa National Forest, was held in late summer 1982, near Bemidji, Minnesota. There were over 85 attendees representing federal, state, county and private wildlife interests throughout the western Great Lakes region, including Canada.

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CONTENTS

MANAGED WETLAND HABITATS FOR WILDLIFE: WHY ARE THEY IMPORTANT?

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Wetland habitats provide life necessities for a myriad of wildlife. Many species not normally associated with wetlands also acquire important nutrients or use the cover available in wetlands during some phase of their annual cycle. The most obvious requirement that wetlands provide wildlife is the available food for reproduction, growth, and survival. Currently we know more about how birds and mammals exploit wetlands than how fish, amphibians, reptiles, and invertebrates do. I will use birds as primary examples in this paper because their nutritional and habitat requirements are more thoroughly understood than for any other vertebrates.

New evidence with birds provides a clearer understanding of the many relations among the resources available from wetlands at different latitudes and the adaptations that allow migrants to acquire life necessities. Weller (1975) has suggested how wetlands at different latitudes provide the resources required by waterfowl at different periods in the annual cycle. Dabbling ducks use freshwater wetlands and consume more invertebrates during the reproductive period in southern Canadian provinces but migrate to southern inland and coastal wetlands and consume a larger proportion of plant materials in fall and winter.

The potential for reproduction or survival of some migratory species may be strongly influenced by the conditions encountered within different wetland types at different latitudes or areas. For example, the reproductive success of the purple heron (*Ardea purpurea*) in the Netherlands is closely related to the winter wetland conditions of the Senegal and Niger river deltas in western Africa (den Held 1981). Likewise, the availability of high quality winter wetland habitat within the Mississippi Alluvial Valley is closely correlated with the reproductive success of mallards (*Anas platyrhynchose*) in North America (Heitmeyer and Fredrickson 1981). These recent findings complicate management of local or region wetland complexes because response by some target species may be controlled, in part, by conditions well outside a management area. These findings also demonstrate that we need to know the life histories and requirements of species we want to manage. We also need to know the role of local wetlands in providing specific requirements at important periods in the annual cycle.

The greatest potential for developing impoundments is in regions where former wetland watersheds have been modified by agriculture, or in areas of undulating topography where riparian lands are abundant. However, modifying natural wetlands by impoundments may result in radically different hydrologic regimes that are not ecologically sound. For example, waterfowl select natural wetlands over impounded water such as farm ponds in Oklahoma (Heitmeyer and Vohs 1981). Impoundment of streams in the North Central forested region can be either beneficial or detrimental depending on the watershed, the species involved, and the specific habitats lost or gained. The goal of this paper is to summarize the importance of man-made or natural wetlands for wildlife and to suggest ways to manipulate man-made or man-altered habitats to meet the life necessities of wildlife.

WETLAND HABITAT LOSSES AND DEGRADATION

Wetland losses have an obvious impact on wildlife but the results of wetland degradation on wildlife populations are also serious. Even though individual wetland basins may remain intact and hold water, their productivity may change so dramatically that resources required for wildlife are reduced or no longer available.

The lack of baseline data on the original area, quality, and distribution of different wetland types in North America precludes an accurate appraisal of cur-

rent wetland losses and degradation. But losses within the prairie pothole region of the north central United States have been estimated at 51 percent between 1900 and 1955 (Schrader 1955) and 75 percent between 1850 and 1977 (U.S. Department of Agriculture 1980). In Iowa where agriculture has been highly developed, at least 95 percent of the original natural wetlands have been lost (Bishop 1981).

Minimal losses of waterbird production through complete drainage and conversion, partial drainage, and flooding of Type IV prairie potholes have been estimated to exceed 90 million nests (Weller 1981a). Awesome habitat losses and decreased productivity face the prairie wetland manager whose role is to maintain habitat and wildlife for a growing demand by consumptive and nonconsumptive users.

Because wetlands in the northern prairies are used by waterbirds for nesting and brood rearing, losses of these northern wetlands have high public visibility. Losses of wetlands used during the migratory and wintering phases of life cycles are more obscure. Most migratory birds are more social during the nonbreeding period and often form large aggregations. When aggregations utilize habitats where they are readily visible, they can mask the actual status of a continental population or give the impression that certain habitats play a more important role than they do. The importance of wetland complexes cannot be overstated. Each species requires many different resources throughout its life cycle and any individual wetland is unlikely to meet all of these needs.

Losses and degradation of winter wetlands are no less severe than on breeding areas. In Missouri lowland hardwood wetlands decreased by 96 percent from 1 million ha to less than 40,000 ha between 1870 and 1976 (Korte and Fredrickson 1977). More importantly, of the remaining area only about 5,500 ha function as the original ecosystem once did because forested tracts have been drained or isolated as tracts less than 100 ha in size. Similar losses have occurred throughout the Mississippi Alluvial Valley. Recent estimates indicate that less than 2 million ha of the original 10 million ha remain (MacDonald *et al.* 1979).Not only have areas been greatly reduced but nearly all sites in the Mississippi Alluvial Valley are subjected to adverse impacts such as turbidity, pollutants, and excess runoff that degrade the remaining wetland habitats (Fredrickson 1980a, Schmitt and Winger 1980). Managers face major challenges to provide adequate high quality winter wetland habitats for wildlife in the Mississippi Alluvial Valley because only 293,000 ha are held in public ownership (Fredrickson 1980a).

Losses and modifications of Gulf Coast wetlands also have been severe. Coastal wetland losses have reached 10,000 ha/yr in Louisiana alone (Galiano 1981). Mississippi River channel modifications have reduced or altered river delta formation because silt is transported and carried directly to the continental shelf in the Gulf of Mexico rather than being dropped in near-shore areas. Wetland degradation is also extensive. Channels dug for oil and gas exploration have allowed salt water to intrude from the Gulf Coast into marsh areas. Increasing salinities have reduced freshwater marsh habitat by 90 percent. Heavy urban and industrial use of freshwater from wells in coastal areas has increased salinities in some areas as well. As salinities increase, waterfowl use has dropped precipitously.

Degradation of wetland habitats comes in a variety of forms. We generally think of degradation as resulting from developing of agriculture, industry, mining, the military, transportation, urbanization or flood control. Thousands of potholes have been bisected by roads. Silt laden runoff from fields, roadbeds, construction sites, or mines, increase turbidity and fill wetland basins (Fredrickson 190a, Bellrose *et al.* 1979 Weller 1981a). Untreated sewage from feedlots and urban areas cause eutrophication that can enrich or degrade an area for wildlife use (Starret 1971, Swanson 1977). Enriched systems may shift algal and invertebrate communities to less desirable forms that are less advantageous to invertebrate predators or cause increased BOD and resulting fish or invertebrate die-offs, or both. Pollutants from agriculture or industry cause die-offs, reduce wildlife survival and reproduction, or make wild game unfit for human consumption (Baskett 1975, Krapu *et al.* 1973). Channel modifications for flood control and transportation often change the composition of vegetation outside project areas (Fredrickson 1979a, 1980b).

Managers also must realize that manipulating a wetland to enhance a certain habitat or to attract a certain species, may degrade it over the longer term. Managed wetlands often lack the seasonal and long-term water fluctuations that revitalize the system and maintain high productivity. The lack of precise water control, political or public pressure, inadequate or incorrect management information, climatic conditions, beavers, or conflicting management goals are but a few obstacles to successful management. Some wetlands have been flooded for recreation (Errington 1963), whereas others are used as a source of water for irrigation (Bolen 1982). Stabilized water levels reduce productivity and may result in vegetation-choked or alternately vegetation-free basins that are not attractive to nesting birds (Weller and Fredrickson 1974). Deeply flooded basins often lack emergent vegetation or only contain the most water-tolerant forms.

In southern forested wetlands some changes related to management practices are so subtle that 20 or more years may pass before degradation is obvious (Fredrickson 1979a, 1980a). Green-tree reservoir management is a common practice where levees are built around oak flats. When flooded during the dormant season, these areas provide mast and other native foods for ducks. Typically such managed forests are flooded earlier and deeper than would occur naturally. After many years of such management, reproduction of desirable food producing trees is nil. Mast production is reduced and mast producing trees suffer increasing mortality (Black, personal communication). During the early years of managed flooding these sites are of great value for wood ducks (*Aix sponsa*) and mallards, but after flooding degrades the habitat, the forest cannot be revitalized or replaced quickly to provide the habitat or foods normally utilized by these species in fall and winter.

WETLAND DYNAMICS

The abundance and distribution of plants and animals associated with wetlands are controlled by soil nutrients, climate, the quality and quantity of water, hydroperiod, and hydrological regime (Fredrickson 1982). The hydroperiod or seasonal and long-term availability of water is undoubtedly the single most important factor that influences habitat conditions and the subsequent use by wildlife (Carter *et al.* 1979). Seasonal and long-term changes in water conditions are well known on the prairie breeding grounds. More wetland basins are flooded and water depth is usually greater in spring than in summer or fall. Only the deepest basins may be filled in dry years but all or nearly all basins are filled in the wet years.

Natural wetlands are dynamic systems with constantly changing water conditions that influence the availability of nutrients for wildlife. Wetlands regularly occur as complexes where basins with different sizes and depths have plants with varying life-forms (Weller 1979, 1981b; van der Valk and Davis 1979). Each wetland type may provide habitat or nutrient resources for different groups of wildlife or provide different requirements for a single species during the annual cycle. Wetland complexes are no less important in southern regions when different habitats in close proximity to one another provide escape cover or nutrients for molt, migration, survival, fitness for reproduction, and other life history requirements (Fredrickson 1979a, 1980a; Heitmeyer and Fredrickson 1981). Southern wetlands are generally associated with riverine or coastal systems and different wetland types usually occur along a continuum rather than as discrete wetland basins (Bedinger 1979).

Regional patterns of southern inland wetland dynamics are demonstrated in Oklahoma (Heitmeyer and Vohs 1981). The seasonal and long-term patterns of precipitation determine the dynamics of Oklahoma wetlands. Seasonally the numbers of flooded basins are lowest in fall and early winter and basin numbers continue to increase in late winter and throughout spring and reach a peak in early summer. Fluctuations in the number of basins increases or decreases depending on the seasonal and long-term changes in rainfall locally and regionally. Peak number of wetlands did not occur in each of six physiographic provinces of Oklahoma during the same year or season (Heitmeyer and Vohs 1981). The degree of change between low and high water conditions within the same province during 1978-1980 indicated increases in basin numbers from 24 to 146 percent and increases in surface area from 89 to 324 percent. A similar degree of change occurred between numbers of May and July ponds in the prairie provinces of Canada (Strata 25-40) from 1955 to 1979 (U.S. Fish and Wildlife Service unpublished data). Such differences in regional dynamics of wetlands influence wildlife use and may explain different patterns of seasonal migratory movements.

Productivity (kg/m^2) of biomass in southern swamp forests is related to type of flooding regime (Odum 1979). Stagnant water or prolonged flooding results in the lowest productivity whereas peak productivity occurs on sites with seasonal flooding. Likewise, tidal fresh wetlands that occur in the upper reaches of riverine estuaries are among the most productive wetlands because vegetation benefits from moderate tidal energy but plants are subjected to less stress from salt or storm tides (Whigham *et al.* 1978).

The consistent relations between productivity and water dynamics regardless of wetland type or latitude clearly indicates that effective and well-timed water manipulations are of central importance to wetland management. If managed areas are to provide essential wildlife habitat when total wetland area is decreasing and the remaining wetland area is subjected to further degradation, manipulations should (1) shorten long-term water cycles, (2) provide essential habitat both in and out of phase with natural complex cycles, (3) prevent stabilization of water levels, and (4) make food available during critical periods in the annual cycle.

REQUIREMENTS FOR ENERGY AND COVER

The adaptations of species that utilize wetlands have been shaped by the availability and distribution

of energy within wetland systems. For simplicity, the term energy will be used in its broadest context to include other nutrients as well as energy. The constantly changing availability of energy during the year provides proximate cues that control the timing of events in the annual cycle of plants and animals. The irregular fluxes in energy related to the long-term changes in the hydroperiod ultimately control morphological and other adaptations required for reproduction and survival. The availability of energy enables animals to exploit these wetland habitats as they reproduce and grow and thus ensures their survival.

The availability of energy in wetlands is ultimately related to the supply and internal cycling of nitrogen and phosphorus in the system (Kadlec 1979). Nutrients are available internally from sediments, water, and from decomposition processes. Wetlands also receive important inputs from the surrounding watersheds (Davis *et al.* 1981, van der Valk *et al.* 1979). Controlling these nutrients requires careful attention to water regulation because the mobility of phosphorus and denitrification processes are related to rapid and frequent water level fluctuations.

Reproduction, growth, and survival of wildlife are possible only if adequate energy is available in each of the wetland types used during the annual cycle or if energy can be transported among wetland systems. Our current level of research has provided a baseline understanding of changes in weights and body composition of waterfowl during reproduction and to other energy-demanding periods of the annual cycle. Identification of energy requirements is critical to the development of management options but understanding and conditions that make resources available within wetland systems is no less important for effective management. Managed systems are most valuable when they continue to provide wildlife with energy above maintenance levels during critical periods in the annual cycle as well as over a series of years.

Changes in the seasonal availability of energy are most obvious at high latitudes where ice cover makes energy unavailable. Aquatic foods are locked within frozen wetlands and food production processes are slowed or cease. Most northern hemisphere vertebrates that use high latitude wetlands migrate to milder climates where energy is more readily available during their nonbreeding season. Special adaptations allow some species to nest in high latitudes. Arctic nesting snow geese (*Anser caerulescens*), Canada geese, and black brant (*Branta bernicla*) carry energy from more southern wintering and migration areas to the breeding grounds (Ankney and MacInnes 1978; Raveling 1978, 1979). These body reserves enable geese to lay eggs before food is readily available locally on the breeding areas. The early timing of laying allows eggs to hatch at a time when food resources will be in abundance for developing offspring. The availability of sunlight for long periods daily allows young to develop rapidly during the short arctic summer when wetlands are ice free. Use of resources by wildlife at different latitudes indicates that wetlands should be viewed along a continuum. Even though resource use may occur during a short period in the annual cycle at a given location, the resources acquired may be critical to many birds such as migratory geese that nest or winter elsewhere.

Concentrations of waterbirds are suggestive of pulses of readily available energy resources within wetlands or on adjacent uplands. Peak numbers of diving ducks exceeded 0.5 million birds on the Mississippi River at Pool 19 near Nauvoo, Illinois in the 1960's (Thompson 1973). Plant resources were few but the birds readily exploited a large population (over $100{,}000/m^2$ of fingernail clams (*Sphaerium transversum*) In Missouri, grackles (*Quiscalus quiscula*) and killdeer (*Charadrius vociferus*) concentrated on a seasonally flooded impoundment to exploit a physid snail population that was vulnerable to predation during a drawdown (Reid 1983). Ninety-six percent of the isolated snail population was consumed in a few days.

In many cases foods are closely associated with aquatic plant communities. Canvasbacks (*Aythya valisineria*) concentrated near beds of *Potamogeton pectinatus* and *P. richardsoni*, whereas redheads (*Aythya americana*) concentrated near scattered beds of *Scirpus acutus* and where *P. pectinatus, Ruppia occidentalis,* and *Chara* sp. predominated in a large southern boreal lake in the late summer molting period (Bergman 1973).

Although we often think of plants as providing energy directly in the form of seeds and leafy material, they also may serve as important substrates for invertebrates. Voigts (1976) has shown the importance of vegetation substrates for invertebrates in glacial marshes. Birds that concentrate on sites with plants lacking food value in seasonally flooded impoundments in Missouri probably are exploiting invertebrates (Taylor 1978, Fredrickson and Taylor 1982, Reid 1983 unpublished).

Foods are of primary importance but life cycles cannot be completed without adequate cover. Successful nesting requires vegetation with the desired vertical and horizontal structures. Glacial emergent wetlands of the upper Midwest have seasonal changes in area and interspersion of cover and water (Weller and Spatcher 1965, Weller and Fredrickson 1974, Weller 1981b). Vegetation changes are related to change in

water levels and to muskrat populations. Ideal cover conditions that support rich bird faunas with maximum numbers of individuals occur when vegetation is patchy and the ratio between cover and water is about 50:50 (Weller and Fredrickson 1974). Number of taxa, biomass, and density of invertebrates increased dramatically 4 weeks after cattails (*Typha latifolia*) were cut and removed from plots in southern Manitoba (Murkin *et al.* 1982). Feeding by waterfowl had a higher frequency on the plots once invertebrate biomass increased and the best use was associated with a 50:50 water-cover ratio (Kaminski and Prince 1981).

Shorebirds generally are associated with unvegetated or sparsely vegetated habitats but recent evidence suggests that common snipe (*Capella gallinago*) forage in wet habitats with more robust upright cover during midday (Rundle 1981). In contrast to inland migrant shorebirds, rails center their activities on sites with robust upright vegetation and shallow water (Rundle and Fredrickson 1981). Maintaining upright vegetation is relatively easy in fall but by spring most upright vegetation has deteriorated because of flooding, heavy wildlife use, muskrat eat outs, or weather.

An understanding of the fluctuations in body lipids and proteins during the annual cycle is important in formulating management practices. Sophisticated technology is available to monitor fatty acids and amino acids of foods as well as their content within wildlife. A more complete understanding of the availability of imortant amino and fatty acids and how they are utilized by wildlife will enhance our abilities to provide maximum benefits to wildlife. Increasingly effective and precise management of wetland habitat is essential as wetland areas continue to decrease in size and quality.

IMPOUNDMENTS AND WILDLIFE: MANAGEMENT POTENTIAL

Wetland impoundments for wildlife can be classified in a variety of ways. Some impoundments were designed and constructed for wildlife whereas others are used by wildlife but were constructed or resulted from some other purpose. Highway barrow areas, stock ponds, and cooling reservoirs for power plants provide a few examples of impoundments built for purposes other than wildlife. Their value is often reduced because of location, size, and conflicting uses (Ruwaldt *et al.* 1979, Lokemoen 1973, Oetting and Cassel 1971, Anderson 1978). Impoundments specifically developed for wildlife are either modifications of natural wetland basins or are designed and constructed for wildlife on sites where wetlands are non-existent.

Management potential is usually best on sites developed specifically for wildlife but nearly any man-made wetland site has some management potential. In Texas there are an estimated 500,000 stock ponds with a surface area of 1 ha or less (U.S. Department of Agriculture 1980). These small ponds and larger impoundments of 1 ha or more account for over 1.5 million ha of surface water. Areas of such magnitude can provide potential habitat for a number of wildlife on a statewide basis. Nevertheless, management problems associated with water availability, (excess or insufficient), water control, disturbance, or regional politics, often reduce potential use on areas whether or not they were designed specifically for wildlife.

Where hydroperiods can be manipulated, managers have opportunities to duplicate natural water fluctuations or to provide important habitats out-of-phase with natural hydroperiods. Experimentation in Iowa indicated the bird response to habitat conditions provided on a managed Type IV glacial wetland was excellent during a regional drought when surrounding natural wetlands had reduced bird use (Weller and Fredrickson 1974). Manipulation of single wetland basins can never duplicate the quality of dynamics of natural wetland systems. Nevertheless, management of groups of man-made or man-modified wetland basins can more closely duplicate the habitats available in natural systems. For example, in southeastern Missouri, groups of seasonally flooded impoundments are manipulated regularly to attract and hold a diverse wildlife fauna including over 140 species of birds and especially waterflowl, herons, rails, and shorebirds, as well as mammals, amphibians, and reptiles (Rundle and Fredrickson 1981, Fredrickson and Taylor 1982). Although wetland use by a variety of wildlife may remain high, shifts in the composition of wildlife that respond to managed conditions should be expected. When management is targeted for shorebirds rather than ducks, waterfowl numbers remain constant by the composition of waterfowl species that are attracted to the management area may change and favor those that use shallow water and mudflats, such as Canada geese (*Branta canadensis*) and pintails (*Anas acuta*) (Rundle and Fredrickson 1981).

In most cases the value of management has been measured by either increases in numbers or in species richness. Habitat changes resulting from wetland management might only make birds more visible or attract certain abundant species. Habitat needs for other species with critical habitat may no longer be met or entire riparian zones or certain water depths might be lacking after developments. Better methodology in monitoring changes resulting from impoundment development are critical to refining management procedures.

Impoundments at northern locations are often managed for breeding birds. Providing food resources comes first but nesting cover must be present as well. Management of impoundments in the south is often centered on providing food resources for migrant and wintering birds. Wildlife response to drawdowns in Missouri suggest that diverse wildlife use is possible when manipulations are well timed. Early in the season deeper waters (greater than 25 cm) supply migrants such as grebes, coots, and diving ducks with suitable habitats. Reducing the water level (25 to 5 cm) as spring progresses provides suitable foraging areas for later migrants such as shovelers (*Anas clypeata*) and blue-winged teals (*Anas discors*). Holding water levels between 5 and 25 cm provides extensive foraging area for herons. Reducing some areas to mudflats attracts shorebirds and raccoons (*Procyon lotor*) and eventually carrion feeders such as common crows (*Corvus brachyrhynchos*) and turkey vultures (*Cathartes aura*).

Management options for wetlands are many but most require a basic understanding of nutrient cycling, plant ecology, and animal population dynamics. Rapid changes within wetland systems dictate that conditions must be monitored continuously in managed basins. One final note of caution: the best management decision within a given location may be to maintain existing wetland basins as unmodified entities where natural forces are allowed to operate without interference from man. Wetland function is so complex that our management desires to meet requirements for a target species may preclude maintaining the basin as a dynamic productive wetland. Management efforts are best centered on habitats that are man-made or on natural habitats that were subjected to perturbations not associated with wildlife management. Only then can managers meet the responsibility to the resources and users alike.

Managers in the north central region have unique opportunities and responsibilities for providing wetland habitats in forested regions. The selection of impoundment sites, development to enhance the productivity of the forested ecosystem, and adequate pre- and post-impoundment monitoring provide many management challenges. Because wetlands are influenced by activities within their watersheds, on adjacent uplands, and even at distant locations, wetland management must be part of a more comprehensive management plan. Timber harvest sites and practices can influence runoff and sedimentation; high recreational demands, and the location of roads, camps and trails determine the level and location of disturbance; and distant power plants can influence water quality. Attention to the dynamics of wetlands and outside influences will assure that these managed wetlands will remain productive, benefit a rich wildlife fauna, and provide much public enjoyment at a reasonable cost. This workshop should be an important step in meeting these challenges.

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WETLAND MANAGEMENT: PUBLIC CONCERN AND GOVERNMENT ACTION

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Public attitudes about wetlands are changing and ve now have a better appreciation for wetlands and heir values to the public. Despite substantial efforts nade to protect wetlands, losses have been acceler-ıting as a result of a combination of both natural and ıuman activities.

STATUS OF WETLAND RESOURCE

The last U. S Fish and Wildlife inventory of wet-ands in the U. S. (Circular 39, 1956) indicates that here were some 12.4 million acres in the north central rea. Since 1954 (when the inventory was made), some reas have lost substantial amounts of wetlands while thers have not changed significantly. Iowa, Illinois, nd Missouri have lost at least 25 percent of their vetlands in the past 20 years. In Michigan, Minnesota, nd Wisconsin, 5 to 10 percent have been lost in the ast 20 years.

Wetland drainage in the prairie pothole region is ccurring at the rate of 1 to 2 percent per year--some 5,000 to 20,000 acres per year in Minnesota, North Dakota, and South Dakota. About 2 million acres of vetlands remain in North Dakota of an original 4.5 nillion acres. By the year 2000 there will be a further oss estimated at 0.6 to 0.8 million acres. This is sig-ificant because North Dakota hosts some 40 percent f the breeding ducks in the lower 48 states. In Iowa, 7 percent of the wetlands have been drained.

Bottomland hardwoods have been cleared at an av-rage of some 165,000 acres per year over the past 40 ears. In the lower Mississippi Valley, bottomland ardwoods have declined from 12 million to 5.2 million cres. With current trends only 3.9 million acres will emain by 1995.

This loss has not only affected the 2.5 million wa-erfowl hunters, but the commercial fishery, the fur-earer harvest, habitat for endangered, threatened, nd non-game species, the hardwood timber resource, nd has reduced natural flood retention. The fish and wildlife service has stated that, "There is no indication that the ongoing alteration of wetlands will cease or be reduced in the near future."

A major share of the wetlands are being drained as a result of agricultural and other development. The rich bottomland soils are extremely productive and bring a higher rate of return when planted than if left in wetlands or managed for hardwood timber. Annual returns for managed hardwoods are less than half the return that can be realized for corn or soybeans.

Losses of wetlands have taken their toll on fish and wildlife. Breeding mallard populations, after some 20 years of relative stability, are declining at an average rate of about 3 percent per year. Incentives to drain marginally unproductive wetlands increase as the cost of land and prices for agricultural products increase, and as technology improves.

WETLAND VALUES

Productivity.--Wetlands are among the most productive ecosystems. They support a wide diversity of aquatic and terrestrial life; studies in salt marshes show production of 10 tons of organic material per acre per year--a yield that exceeds the most fertile agricultural lands. From 70 to 90 percent of the commercially important fish and shellfish depend upon coastal marshes.

Water Quality.--Wetlands act as nutrient traps and control sediment. In 1981, 96 wastewater treatment facilities in the Lake States were utilizing wetlands, principally cattail marshes. Tertiary treatment benefits at one plant were estimated at $80,000 per year. The Forest Service has a test treatment plant in cooperation with the State and City of Drummond, Wisconsin.

Flood Control.--Wetlands provide a natural means of flood control by retaining water during periods of high runoff. Studies have shown that wetlands can

retain 50 to 80 percent of total runoff. A study of Wisconsin watersheds concluded that flood flows are 80 percent lower and sediment yields are 90 percent lower in basins consisting of 40 percent lake and wetland areas than in basins with no lakes or wetlands. Many of the State and national forests significantly reduce floods. The Corps of Engineers estimated that flood control benefits afforded by wetlands in the Charles River basin (Mass.) were worth $2,000 per acre per year.

Groundwater Recharge.--The Cedarburg Bog in Southern Wisconsin supplies water to suburban Milwaukee. The 5 square mile wetland controls groundwater supply for an area of about 165 square miles. A Massachusetts study showed that the value of one acre of wetland for groundwater recharge was $100,700.

Fish and Wildlife.--Wetlands provide habitat for all types of wildlife, those used consumptively as well as nonconsumptively. They provide critical habitat for some 80 of 276 species considered threatened and endangered. The 10 to 12 million ducks that breed annually in the lower 48 states are direct products of wetlands. Many species are dependent upon riparian habitat. Wetlands support over 40 percent of the nation's annual fur harvest. In 1975, 8.3 million Americans hunted migratory waterfowl, and spent $950 million for this wetland-dependent activity. Wetlands support a variety of fish and fishing use. In 1980, 36.4 million freshwater fishermen spent 710 million days and $7.8 billion pursuing their sport.

WETLAND REGULATIONS

Regulations currently affecting most States begin at the national level, run down to the State level, and through zoning ordinances, extend to the local level. In Wisconsin, for example, these include:

1. Section 404 of the Federal Clean Water Act (PL 95-217) which regulates the disposal of dredged materials, or the placement of fill into wetlands adjacent or contiguous to lakes, rivers, and streams, and includes other wetlands with special values. It is administered by the U. S. Army Corps of Engineers and the Environmental Protection Agency.

2. Section 10 of the River and Harbor Act of 1899 regulates any work in, over, or under navigable waters. It affects wetlands adjacent or contiguous to navigable waters. It is administered by the U. S. Army Corps of Engineers.

3. State statutes (e.g., Wisconsin Chapter 30 and 31) that regulate alteration of navigable waters involving wetlands contiguous to navigable waters and below the ordinary high water mark. These are administered by State DNR's.

4. Endangered species laws, such as the Federal Endangered Species Act, and state endangered species laws protect against the destruction of habitat, including wetlands, harboring endangered species. The Federal Endangered Species Act prohibits federal funding of actions which jeopardize the existence of endangered species. State statutes prohibit the taking, processing, or selling of endangered plants or animals.

5. Shoreline zoning, established under state statutes, such as the Water Resources Act of 1965 (Section 59.971) of the State of Wisconsin. This state law requires counties to enact shoreline regulations, including zoning provisions, land controls and enforcement. Under this statute, the Wisconsin DNR adopted a regulation (NR 115) to protect wetlands within shoreland areas of unincorporated areas. If the counties fail to adopt an ordinance, the DNR will adopt an ordinance for the counties.

6. Flood plain zoning, such as under Wisconsin Statutes (Section 87.30) requires flood plain zoning for areas where serious flood damage is probable. These laws regulate activities that might interfere with discharge of floodwaters or increase the extent of flood damage. They can be used to prevent conversion of wetlands for uses considered detrimental to the flood plain. Some urban development can be controlled. The legislation is intended to permit preservation of flood plain wetlands for their flood storage capacity. In Wisconsin this law is administered by the County Planning and Zoning Administrators.

7. Agricultural conservancy zoning--on the State and local level, regulates non-farm development in zoned areas and is adopted at county and town discretion. It protects wetlands, as well as farmlands, from conversion to other uses, and is chiefly designed to stop urban development. It is generally administered by the County.

STATE LAWS

Wisconsin.--Various attempts have been made to enact legislation to protect Wisconsin's wetlands. In 1977, legislation was passed requiring the Department of Natural Resources to prepare maps showing all wetlands in the State which were 5 acres or more in size. This was referred to as the Mapping Bill.

Michigan.--Michigan passed a Wetlands Bill (Act No. 203) in January 1980. Starting in October, 1980, certain activities in specified wetland areas required a permit from the Michigan DNR. This included wetlands contiguous to lakes, rivers or streams, as well as wetland areas of 5 acres or more in 17 counties of over 100,000 population. Other counties and areas would come under permit requirements when a wetland in-

ventory was complete, unless the wetland areas were designated "essential." Michigan's law exempts farming, silviculture, and harvesting of crops, including timber.

Minnesota.--Minnesota has a wetlands permit program, called Minnesota Public Waters and Wetlands Permit Program. The program applies to types 3, 4, and 5 wetlands (Circular 39) and covers projects involving damage, filling, dredging, channelizing, culverts, etc. Permits are not required for beach sand riprap, boat launching ramps, or seasonal docks if certain conditions are met.

WETLAND LEGISLATION

Legislation protecting wetlands has not been suc-:essful for several reasons. The most significant in-:lude the following:

Poor Definition of Wetlands.--Definitions have ·anged from those based on the Fish and Wildlife Ser-/ice Classification (Circular 39) to those areas com-nonly called marshes, swamps, bogs or wet meadows, ›r "poorly drained" soils where aquatic vegetation is lominant. Agricultural interests have resisted these lefinitions as ambiguous. A rather precise definition ›f wetlands is necessary to describe the areas for which ›rotection is intended.

Method of Regulation.--Various interest groups have ıdvocated control at the local level while other groups ıave been proponents of State (DNR) control. Various egislative bills (ex. Wis. AB 604, AB 92, SB 320) have ›roposed a permit system, while others (AB 515 and ˋB 555) proposed a "restrictive order" approach, vhich could be initiated by a signed petition. Tax ›reaks, easements, purchase or private wetlands, and ourt actions to determine a "taking of property" have ·een used to compensate landowners for protecting vetlands. Often these differences have served to keep ıdividual groups in disagreement, making wetland egislation difficult to enact.

Exemptions.--Legislation has often contained lan-uage so restrictive that most uses would have been rohibited unless a permit were obtained. Special in-erest groups have lobbied and written specific ex-mptions into the bills. As more exemptions are added, etland preservation groups withdraw their support.

Other.--Other factors affecting enactment of wet-ınd legislation include size of regulated wetlands, uffer zones surrounding the wetlands, required res-›ration of wetland areas unlawfully "altered," incon-istencies between nonexempted and exempted ctivities, and permit procedures.

Wetland legislation can best be enacted and enforced where a designation procedure for defining the wetland areas and requirements for use are set forth. In this way, an application for use can be measured against established standards. Prior studies and designation provide a basis for distinguishing the amount of protection necessary. A critical wetland could be set aside from all use while some areas might be subject to limited protection. A Department of Interior study recommends that enabling statutes define wetlands with "considerable specificity." This is necessary to provide precise legal criteria for mapping wetlands and to determine whether particular lands and development sites are in or out of regulatory boundaries.

Wetlands legislation, to be enacted, must ensure:

1. That prior regulations and controls be coordinated to avoid overlapping jurisdiction and confusion.
2. That land-use regulations such as control of wetland use provide for local input and planning.
3. That regulations recognize the physical variation of land or ecotypes over a geographical area.
4. That the impacts on social-economic patterns of local areas be considered in any regulation.

Wetland Classification

Opposition to wetland legislation has often involved the definition of wetlands. Proponents of legislation may clearly visualize the types of wetlands they desire to protect; however, landowners, agriculturists, and others foresee broader interpretations which might result in restrictions being applied to lands not originally intended. The definition of a wetland is difficult because of the diversity, and lack of a clear line between "wet" and "dry" lands. However, it is important that a universally accepted classification of wetland be adopted so that public and private groups can understand and support wetland protection efforts.

Circular 39, based on the 1954 inventory, provided a good basis for initial surveys of wetlands. Much of the legislation passed by Congress to date refers to wetland types defined by Circular 39. However, Circular 39 is now considered inadequate. Recognizing this, the Fish and Wildlife Service initiated a National Wetland Project (1975-79) to devise a wetland classification system that could be applied consistently on a national basis. This effort resulted in the new classification system defining wetlands as "land where the water table is at, near, or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes." Many groups consider this definition too broad, and its use, *without qualifications*, in passing regulatory legislation, could

lead to public controversy. Agricultural interests, for example, view this with concern, because lands defined as wetlands may be farmed during dry periods. However, it is the classification of specific wetland types, rather than the broad definition of a "wetlands" that is used to regulate and protect public wetlands. For example, Minnesota's DNR, under their permit program, follow the guidelines found in Circular 39 to define wetlands that are regulated and protected under Minnesota law. These wetlands, "include and are limited to all types 3, 4, and 5 wetlands that have been designated as 'public waters,' which are 10 or more acres in size in unincorporated areas, or 2½ or more acres in size in incorporated areas."

National Wetlands Inventory

National Wetlands Inventory (NWI) has classified and mapped wetlands throughout 24 percent (715,000 square miles) of the lower 48 States and 3 percent of Alaska. In the "lower 48" these maps cover the coastal areas, Great Lakes, and the major river systems. As of April 1982, the Fish and Wildlife Service distributed over 125,000 copies of available maps. These wetland maps serve as a planning aid to development interests as well as local state and federal agencies. The Corps of Engineers also use the maps as an aid in administering the regulatory program since the waters and wetlands under the Corps; jurisdiction are part of the wetlands mapped by the Service. This wetlands inventory will provide a trend analysis to document changes in our Nation's wetlands over the past 20 years. These maps are also used in the administration of the Fish and Wildlife Coordination Act. This analysis is scheduled to be completed late this year.

CURRENT PUBLIC CONCERNS

Wetlands Protection Under "404"

Legislation (5.777, H.R. 393, H.R. 3083, and H.R. 3962) has been introduced that would dissolve major wetland protection efforts that regulate dredge and fill activities. The proposed legislation would remove wetlands from 404 protection and restrict federal jurisdiction over dredged and fill material to "navigable waters." The Bills would prohibit any federal agency from preventing disposals in non-navigable waters regardless of requirements under other Acts.

The Corps of Engineers' dredge and fill program is derived from section 404 of the Federal Water Pollution Control Act. It requires that a permit be obtained for certain discharges of dredged or fill material into the nation's waters, including wetlands and streams important to fish and wildlife. The permit program is under review by the Presidential Task Force on Regulatory Relief. The Corps, however, has maintained that the permit program is working, and its benefits outweigh its costs, and that concerns about permit time requirements can be resolved.

The Wildlife Management Institute reports that both the Fish and Wildlife Service and the National Marine Fisheries Service have been blamed for lengthy delays in reviewing permit applications. From July 1 to December 30, 1980, the Fish and Wildlife Service reviewed 6,376 applications. It regulates governing dredge and fill material. However, most States do not have adequate review procedures.

This is a critical year for wetlands protection. Congress must reauthorize the Federal Water Pollution Control Act before October 1, 1982, or funds will no longer be available to run the 404 program. When the act is opened for reauthorization, amendments to the Bill weakening section 404 may be added. There is considerable public support for not weakening the Act.

Wetlands Loan Act

In May 1982 the House Subcommittee on Fisheries and Wildlife Conservation and the Environment held oversight hearings to discuss ideas for bolstering protection of the nation's wetlands. Included were legislation to extend the Wetlands Loan Act until October 1, 1988. To date, about $145 million of the $200 million loan has been appropriated. Authority for the program expires in October 1982, and legislation must be enacted to extend the program, or 75 percent of the duck stamp income will be diverted from wetlands acquisition for the next decade to repay the loan.

The Fish and Wildlife Service has stated that an additional 1.7 million acres of wetlands is needed to maintain waterfowl and other bird populations. Proposals for generating funds to purchase these lands include:

1. Give federal tax benefits to landowners who sell wetlands to agencies that preserve the habitat (H.R. 6465).
2. Increase the $200 million Wetlands Loan Act ceiling.
3. Forgive the indebtedness incurred under the Wetlands Loan Act. This would relieve the duck stamp fund of pressure for repayment.
4. Increase the price of the current $7.50 duck stamp. (Currently, this provides about 40 cents more than the $1 duck stamp of the 1930's in terms of purchasing power).
5. Authorize a federal appropriation from general revenues to match duck stamp receipts until the wetland acquisition goal is achieved.

6. Require a duck stamp for persons entering a National Wildlife Refuge for any recreational purpose.
7. Amend the Federal Aid in Wildlife Restoration Act to require money taken under the administrative purposes authority of the Act to be used for wetland acquisition.
8. Amend the Federal Aid in Wildlife Restoration Act to require that funds reverting from States be used solely for wetlands acquisition.
9. Use some of the oil and gas royalties from refuges in Alaska--90 percent of the royalties now go to the State of Alaska, as compared to 50 percent in the lower 48 States.
10. Amend the Land and Water Conservation Fund Act to permit the money to be used to acquire habitat for migratory waterfowl. The Forest Service currently has authority under the LWCF Act to acquire lands for wildlife habitat, including wetlands habitat. This authority was included under amendments to the LWCF Act.

The Wildlife Managment Institute reports that with information from the hearings, legislation will be drafted during 1982 to help the Fish and Wildlife Service meet its wetland protection goals.

NATIONAL WATERFOWL PLAN

A National Waterfowl Management Plan for the United States was issued by the Fish and Wildlife Service in March 1982. The plan defines what is intended to be achieved by cooperatively managing waterfowl in the United States. It provides a basis for developing detailed flyway management plans. The plan identifies three major objectives that must be achieved to reach the goal of maintaining waterfowl populations for the benefit of people. These are:

- Protect and manage the habitat needed to maintain or increase waterfowl numbers.
- Achieve optimum waterfowl population levels consistent with the availability of habitat.
- Provide optimum opportunity for people to use and enjoy waterfowl.

This document sets forth a national goal for waterfowl in the United States. It provides guidance for the U.S. Fish and Wildlife Service, the States, and the other public and private agencies and organizations that work cooperatively in the conservation and management of these birds. It provides a basis for developing detailed management plans for each of the four waterfowl flyways, and contributes to the eventual development of an international North American waterfowl management plan.

The plan is organized around three major topics that encompass most waterfowl management issues: habitat, populations, and utilization. It identifies what needs to be done for waterfowl and how work will be accomplished.

U.S. Fish and Wildlife Service Programs

Fish and Wildlife Service programs undertaken to minimize wetland losses include:

Land Acquisition.--Traditionally, land acquisition has been the primary tool used by the Fish and Wildlife Service to conserve wetland habitat. Funding is derived from several sources, including the Land and Water Conservation Fund (LWCF), receipts from the tax on motor boat fuel, the sale of surplus property, and acquisition through other federal agencies such as the Corps of Engineers. The primary source of funding comes from the Migratory Bird Hunting and Conservation Stamps ("duck stamp"), supplemented by advance appropriations against future sales authorized by the Wetlands Loan Act of 1961. The "duck stamp" provides $15-16 million annually. The Wetlands Loan Act authorizes $200 million of added receipts, of which some $144 million has been authorized.

The goal of the Fish and Wildlife Service is to acquire habitat to support a duck population of 36.3 million. This would equal the population existing during the period 1955-1975. The primary emphasis will be on the conservation of waterfowl *production habitat.* A total of 12.5 million acres of waterfowl habitat will be needed to achieve this objective. The federal share was placed at 8 million acres, inlcluding the 3.5 million acres managed by the Fish and Wildlife Service. That leaves 4.5 million acres to be acquired at the federal level. The Service has purchased in fee or easement about 2.2 million acres toward this goal. Time is running out. Wetland acquisition has been decreasing in response to efforts to balance the federal budget. Fish and Wildlife Service realty personnel have been significantly affected by cuts in federal funding. State funding has also been reduced because of loss of cooperative funds from the Fish and Wildlife Service.

Fish and Wildlife Coordination Act.--The Coordination Act requires that federal water resource agencies give consideration to fish and wildlife in planning and implementing water resource development projects. The Service makes recommendations concerning the extent of possible losses to the fish and wildlife resources, as well as measures to prevent or mitigate losses. The Service also cooperates with state and federal agencies to develop or protect wetlands.

Clean Water Act--Sec. 404.--The Corps regulates the discharge of dredge and fill material into waters of the U.S. The Fish and Wildlife Service is provided an opportunity to review all projects and provide recommendations to the Corps concerning impacts on wildlife and fish. This program has been instrumental in preventing or minimizing losses to wetlands.

U.S.D.I. WETLANDS TASK FORCE

Interior Secretary Watt recently established a private sector task force to advise him on opportunities to protect wetlands. The task force consists of 24 members from industry, national conservation groups, sportsmen's organizations, and Congress. Secretary Watt and Alabama Governor Forrest James, co-chair the group.

The group is divided into five subcommittees to plan and implement wetlands protection strategy in the public and private sectors.

The Task Force will consider such subjects as:

- Ways of bolstering the national conservation effort.
- Private donations of interest in wetlands.
- An increase in the price of the Duck Stamp.
- Matching Duck Stamp receipts with Land and Water Conservation Fund Money.
- Offering landowners state and federal tax benefits to maintain wetlands.
- And other possibilities to improve the status of wetlands with and outside the U.S.

The task force will advise and counsel public and private officials on wetland protection. They will also develop a program to encourage landowners to donate wetlands or easements to state and federal agencies to protect wetlands.

In establishing the group, Watt noted that the federal wetlands protection program, begun in 1929, has not been as successful as would have been desirable, and a new initiative is needed for saving the wetlands from drainage.

SUMMARY

Although wetlands have received increased emphasis by resource agencies, the threats to wetlands are extensive and diverse. The wetlands that once covered 127 million acres in the lower 48 States now number about 80 million acres, and continue to disappear at the rate of 300,000 to 400,000 acres each year.

Interior Secretary Watt has directed the Fish and Wildlife Service to act more aggressively in the purchase of wetland areas which provide important migratory bird habitat using "duck stamp" receipts. Acquisition using other funds will be considered in light of budgetary constraints.

The Fish and Wildlife Service cannot do the job alone. The National Waterfowl Plan does not include opportunities to accomplish national objectives by other agencies. The Fish and Wildlife Service must solidify an active partnership with the other federal agencies, state and local governments, and private groups to achieve the Plan's objectives. Without a coordinated effort the long-term outlook for wetlands is not bright.

HISTORY OF WATER IMPOUNDMENTS IN WILDLIFE MANAGEMENT

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The 1920's and 1930's were times of change for nat- ıral resources in North America. It was beginning to ecome evident at this time that these resources were ıot unlimited. Unchecked habitat destruction and ov- rexploitation were resulting in decreasing popula- ions of wildlife. One of the most notable declines was xperienced by waterfowl. Newspapers were even re- orting declines in waterfowl harvest (e.g., "Poorest luck season on record", Grand Rapids Herald Review, 931).

The first step in the solution of any problem is rec- gnition. Vast areas of wetlands were drained, mostly or agricultural purposes, during the early decades of his century. One of the first discussions of this prob- em in a published public forum occurred in 1938 at he Third North American Wildlife Conference (Page *t al.* 1938). The Conservation Director of the Izaak Valton League questioned the justification for drain- ng 84 million acres of wetlands, and called for ade- uate mitigation of habitat values lost as a result of rater development and drainage. The following year Bourn and Cottam (1939) reported the first study that ocumented the effects on wildlife and plant associ- tions of draining marshes. In their words "... the ırvival of one or all natural plant and animal asso- ations on a marsh (following drainage) may be im- ossible."

However, the period also resulted in the develop- ıent of professional wildlife management (Leopold 933). Wildlife management evolved from the admin- tration and regulation of harvests to the scientific anagement of populations and habitats. The advent f the Federal Aid in Wildlife Restoration Act (i.e., ittman-Robertson Act) in 1937 provided much of the ınding necessary to implement wildlife management ractices needed to restore wildlife habitats, including ıarshes.

First to receive attention in the literature were the peatland marshes that had been drained to promote agriculture (Cox 1939, Dachnowski-Stokes 1939). These lands, at best, often produced only marginal crops and were always prone to fire. After these farming enterprises were abandoned, proposals were made to construct dams in these areas to impound water and restore wetland characteristics to the area. Many large wildlife managment areas came about in this fashion (Cartwright 1946, Nelson 1953, Penfound and Schneidau 1945). Following construction of water impoundment devices and subsequent restoration of water levels, it was felt that these restored wetlands would be most productive if water levels were maintained.

In the early 1940's managers continued to advocate stable water levels throughout the year in managed marshes to maximize waterfowl and furbearer production (Hewitt 1942, Zimmerman 1943). However, initial studies were also completed at this time on how naturally fluctuating water levels affect the vegetation and wildlife associated with wetlands (Bellrose and Brown 1941, Bellrose and Low 1943, Yeager and Anderson 1944). Investigators also began to recommend manipulation of water levels in natural marshes to increase waterfowl and muskrat productivity (Pirnie 1941) and to manipulate wetland habitats (Uhler 1944).

Productivity in many of the large marshes that were restored in the 1930's began to decrease in the 1940's (Hartman 1949), even though the restored marshes often showed higher productivity initially than the original marsh (Penfound and Schneidau 1945).

By the late 1940's it was apparent that most wildlife managers agreed that periodic drawdowns were necessary to maintain high productivity in natural and restored wetlands (Errington 1948, Griffith 1948).

Investigators also began to realize that natural wetlands may not always be highly productive and that impoundments may be constructed to create wetlands where they did not exist before or to enhance management of natural wetlands. Mendall (1949) called for construction of small scale water impoundments throughout " . . . the northern States and southern Canada, west to the Plains States and Prairie Provinces." Speake (1955) recommended the construction of small impoundments in the southeast in 1955. In fact, impoundments had already been built in the east and south that were being managed with periodic drawdowns (MacNamara 1948, and 1949, Penfound 1949, Truax and Gunther 1951).

Waterfowl censuses conducted in 1947 and 1948 indicated that the long downward trend in the continental waterfowl population had been stopped (Mendall 1949). Large-scale draining of marshes had been slowed; drained wetlands had been restored; and intensive scientific management of wetlands for wildlife production had been initiated. All contributed to stem the decline of waterfowl populations.

In the late 1940's and early 1950's the use of small impoundments as a wildlife management technique gained wide acceptance. Use of water impoundment techniques raised many questions about the ecological processes and consequences of constructing and managing impoundments. However, the first study reported in the literature that addressed the ecological relations of water impoundment involved beaver dams and their effect on trees (Wilde *et al.* 1950). The results indicated that ferrous iron accumulated in impoundment soils, which led to the fixation of phosphorus in a insoluble form. The authors further stated, " . . . the impoverishment of soil in available nutrients and its enrichment in growth-inhibiting substances are characteristic of flowage bottoms . . ." forming a basis for understanding why productivity declines in impoundments after several years.

The program to develop small, artificial marshes in New York State exemplifies the efforts of public agencies to improve and expand wetland habitats through impoundment techniques. New York State developed --with the aid of the Fish and Wildlife Service and the Soil Conservation Service--specific criteria used to evaluate potential impoundment sites (Bradley and Cook 1951). Impoundment construction began under this program in 1949. Impoundments were constructed on private land, on a cost-sharing basis, through local Soil Conservation Districts. Proper site selection and well-developed engineering plans were recognized as essential to meeting the objective of wildlife habitat improvement. However, it was also recognized that once the impoundment is constructed and flooded, the major tool for subsequent management was manipulation of water levels.

After the New York State program had been in effect for 4 years, the need was recognized to evaluate the effectiveness of the impoundments and to further refine management techniques. The first of a series of studies designed to do this attempted to describe vegetation changes associated with manipulating water levels in impoundments (Brumstad and Hewitt 1952). Benson and Foley (1956) then evaluated waterfowl use of small impoundments in New York State. They observed that impoundments tended to lose their attractiveness to waterfowl and became less productive after 3 years.

The next study reported from New York State involved soil and water chemistry associated with impoundments (Cook and Powers 1958). The results of that study indicated that reduced productivity of impoundments may be related to accumulations of iron and manganese in the soil. Periodic drainage was advocated to aerate organic bottom soils, thereby reducing iron and manganese concentrations. However, yearly drawdowns are not recommended because excessive nutrient removal will result. The impoundments studied maintained productivity for at least 2 years after drawdown. Another point made was that the drawdowns--especially fall drawdowns--should be maintained through at least one growing season.

A concurrent study in New York State investigated succession of aquatic plants in impoundments (Dane 1959). The results indicated that depth of water level during the growing season was the single most important factor affecting the establishment of plant species. Woody cover continued to survive in impounded areas of shallow water (12-18 inches) that experienced a drawdown in summer.

Emerson (1961a, 1961b, 1962) studied vascular plants on the more than 1,000 impoundments constructed in New York up to 1960 and experimented with artificial establishment of food and cover plants. Although wild rice (*Zizania aquatica*) showed the greatest promise for propagation, the artificial establishment of wetland plants should only be considered after careful evaluation. All conditions must be suitable for the establishment of the plant before planting is started.

Other reports during the late 1950's and early 1960's suggested building impoundments in pairs with a biannual drawdown schedule (Uhler 1956), encouraged developing small impoundments near large water areas to improve hunting and harvest, and recommended obtaining easements or long-term leases for impoundment sites rather than outright purchase (MacNamara

1957). The importance of nongame species in wetlands and the aesthetic values of waterfowl were also beginning to receive recognition (Griffith 1957).

Three of the most significant studies concerning the use of drawdowns in the management of wetland habitats also took place during this period. Harris and Marshall (1963) initiated an intensive study on the effects of water level manipulation on marsh vegetation in northern Minnesota after noting the response of vegetation to drawdowns associated with dike repairs. After studying drawdowns and subsequent reflooding ranging from 1 to 5 years in length, they recommended an early or late summer drawdown lasting 1 year every 5 or 6 years. However, they also stated, "unless present limited knowledge of the consequences of drawdown is enlarged, the technique should be used only for specific purposes with proper control and study."

Kadlec's (1960, 1962) study of the effects of drawdown at the Backus Lake Impoundment in Michigan is still the most comprehensive evaluation of the effects of a drawdown on an impoundment. He concluded that drawdown first " . . produces a temporary abundance of food in the form of seeds of wetland plants; " second, " . . provides suitable conditions for the establishment of emergent cover; " and third, " . . may result in soil improvement and in improved aquatic plant food production upon reflooding." Although he felt that drawdown is a natural and effective method of maintaining the productivity of a waterfowl marsh, he also cautioned that drawdowns should be used only on an individual impoundment basis and that the technique is not a panacea for all marsh management problems.

Bednarik (1963a, 1963b) described the effects of water level manipulation on waterfowl harvest and wetland vegetation on the Magee Marsh Wildlife Area in northern Ohio. Drawdowns were used to induce dense stands of waterfowl food-producing vegetation which subsequently attracted large numbers of waterfowl to the marsh. Flooding was also used to eradicate widespread encroachment of undesirable vegetation.

Other States also began reporting programs of successful waterfowl management through impoundment construction and management (Fuller 1964, Spencer 1963). The State of Maine evaluated their small impoundment construction program from 1958 through 1960 and found it to be a cost-effective means of producing waterfowl. During the 1970's, case history reports on the effect of water level manipulation on vegetation in impoundments (Beard 1973, Mathiak 1971) and waterfowl response to habitat changes continued to appear in the literature.

A series of studies conducted from the late 1950's through the 1970's on glacial marshes in Iowa clearly documented the importance of natural drawdowns in unmanaged marshes (Weller and Fredrickson 1974, Bishop *et al.* 1979). The results indicated that productivity of the entire avian community increased after drawdown and subsequent reflooding. The greatest number and species of birds were present when there was a well-dispersed 50:50 ratio of vegetation to open water. The best way to obtain this condition was to wait 5 to 7 years between complete drawdowns.

From this point on investigations related to impoundments made an effort to address specific ecological phenomena related to wetlands with regulated water levels. Whitman's (1976) study in New Brunswick identified soil, water, vegetation, and aquatic macroinvertebrates as factors that determine level of use of impoundments by waterfowl, and examined correlations between impoundment age and those factors. He also recommended drawdowns every 5 to 7 years to maintain productivity in the impoundment.

Lathwell *et al.* (1969, 1973). and Bouldin *et al.* (1973) made intensive studies on the growth and chemical composition of aquatic plants and the changes in water chemistry in man-made marshes in New York State. Harter (1966) reported on the effect of water levels on soil chemistry and vegetation on Magee Marsh in Ohio. Studies also recommended manipulation of water levels to make seeds and invertebrates located in the bottom soils of impoundments available to waterfowl during periods of high energy requirements, such as pre-egg laying and egg laying (Jemison and Chabreck 1962, Baldassarre 1980). Research also continued to refine the concept that the use of drawdowns in managed impoundments is the most economical and efficient method to maintain desired habitat (Kaminski and Prince 1981).

Impoundments became widely accepted for managing wetlands in the 1960's (Hamor *et al.* 1968). In an effort to expand multiple-use management, impoundment construction expanded on the Chippewa National Forest in 1966 to convert sedge meadows and shrub swamps into primary wetland habitat (Hawkins and Green 1966). To date, 49 impoundments have been constructed on the Forest; construction is planned on about 40 more (table 1) (unpublished information, USDA Chippewa National Forest). Increased waterfowl use of the Forest with managed wetlands has been documented (Mathisen 1970).

Although the importance of managed wetlands to non-game wildlife species and aesthetics were alluded to in the past, production of ducks continued to be the prime objective of wetland management. This began to change in the 1970's and 1980's as other values

Table 1.--*Impoundments constructed for wildlife management on the Chippewa National Forest, north-central Minnesota*

Impoundment name	Area	Date of construction	Cost of construction
	Acres		*Dollars*
Day Creek Lake[1]	85	1956	--
Burns Lake[1]	9	1963	3,000
Seelye Point[1]	15	1964	500
Two Mile Lake	30	1964	5,000
Westbanks I	19	1964	1,000
Sucker Bay	41	1967	6,800
E. Pike Bay[1]	12	1968	1,000
Ball Club	78	1968	6,000
Highway 6	14	1968	7,560
N. Twin Lake[1]	5	1969	500
Loon Lake	119	1969	9,800
Wabana Lake[1]	10	1969	14,000
Welch Lake	33	1970	13,533
Cuba	34	1970	12,700
Grass Lake	70	1970	6,753
Highland Creek	47	1970	7,923
Amik Lake[1]	108	1970	8,240
Bear Brook	58	1970	14,043
Spur Lake	185	1970	18,800
Bag Lake	37	1970	12,061
Multiple use area	149	1971	6,500
Brush Lake	27	1971	13,024
Birch Lake	20	1971	6,782
East Lake	15	1971	5,176
LaCroix I	26	1971	7,240
Ketchum	51	1972	7,469
Pine Tree	113	1973	11,765
Beaver Lodge	77	1973	10,000
Crooked Lake	48	1973	6,000
Fletcher Creek	231	1973	10,000
Hanson Lake	95	1973	13,000
Cub	18	1975	4,000
Six Mile Brook	106	1975	20,000
Snake Brook	44	1975	10,000
LaCroix II	49	1975	8,500
Upper Third River	31	1976	10,000
Ojibway[1]	5	1976	4,000
Egg Lake	49	1976	21,000
Westbanks II	26	1976	8,500
Woodtick	103	1976	36,500
Holland Lake	164	1977	27,000
Jingo Lake	25	1978	20,500
Eel Lake	57	1979	20,000
Experimental Forest	74	1979	22,000
Little Wolf	60	1979	25,500
Sugar Lake	182	1981	27,000

[1]Northern pike spawning area.

gained more attention (Reimold *et al.* 1980). Nonconsumptive use of rails and shore birds has increased (Odum 1977, Ruckel and Sadler 1977) and specific recommendations are now being made to manage impoundments for the benefit of waterfowl other than ducks (Rundle and Fredrickson 1981).

The value of managing wetlands through impoundment techniques was recognized by wildlife managers early in the development of the profession. Management techniques were developed and refined and several studies were initiated over the last 40 years to examine in depth, the ecological relationships of impoundments (table 2). However, effective and economical impoundment management practices are still not known with a great degree of certainty (Lathwell *et al.* 1969). Most of the practices, schedules, and regimes presently in use are based on experience rather than sound scientific principles. The comprehensive, management-based impoundment studies completed to date have indicated that specific, regional, or local investigations are needed to develop management recommendations that will be locally effective (Knighton 1982).

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Table 2.--*Summary of selected impoundment studies conducted in North America*

Source	Wetland description	Drawdown schedule	Objective	Results
Dane 1959	Wildlife ponds, New York	Natural drawdown	Evaluate succession after reflooding	Some emergent food plants established; submergent food plants increased but declined substantially in 5 years; submergents limited by water transparency; emergents limited to 60 cm of water.
Kadlec 1962	Backus Lake impoundments, Michigan	Spring-summer drawdown, fall refill	Evaluate succession after reflooding	Increase in plant nutrients; invertebrate populations reduced; plant species composition not notably affected; most emergent species increased; food production during drawdown was
Bednarik 1963a	Magee Marsh impoundment, Ohio	Spring-summer drawdown, fall refill	Encourage waterfowl food plants	Good production of food plants for 4 years
Harris and Marshall 1963	Impoundments, Agassiz National Refuge, Minnesota	1 to 5 years continuous drawdown	Evaluate succession during drawdown and after reflooding	Emergents invaded wetter soils after drawdown but decreased quickly with reflooding; dense willow established on drier sites in 5 years.
Beard 1973	Impoundment, Murphy Flowage, Wisconsin	October to April	Reduce submergent and floating-leaf vegetation	Drastic reduction in submergents and floating-leaf vegetation.
Weller and Fredrickson 1974	Impoundment, glacial marsh, Iowa	Two summers, one winter	Encourage emergents	Emergents increased during drawdown, then decreased. Pre-drawdown densities in 6 years. Submergents increased after reflooding (2-3 years) then decreased.
Whitman 1976	Impoundments, New Brunswick	New, no drawdown	Study factors associated with aging impoundments	Terrestrial vegetation replaced in one year by sedge and cattail; progression towards rooted aquatics low in food value occurred; submerged and floating-leaf vegetation established, but declined as impoundments aged.
Carney and Chabeck 1977	Impoundment, Louisiana	May through August	Encourage waterfowl food plants	Waterfowl food plants were successfully established.
Klopatek and Stearns' 1978	Impoundment, Theresa Marsh, Wisconsin	Spring to fall	Carp control, determine pre- and post-primary productivity.	Variety of mud flat species established during drawdown; emergents dominated first year after refill.

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WILDLIFE IMPOUNDMENTS IN THE NORTH CENTRAL STATES: WHY DO WE NEED THEM?

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In the north central United States with countless lakes and abundant wetlands, why provide more surface water through construction of impoundments?

This valid and logical question, asked countless times, deserves a valid and logical answer. I will explore the answer by answering four related questions:

1. What is the reason for constructing them?
2. Do impoundments really improve wetland habitat for wildlife.
3. Is there a shortage of natural aquatic communities functioning in a manner similar to impoundments?
4. Can we measure the cost-effectiveness of water impoundments?

I will formulate the discussion using data and experience gathered over 20 years on the Chippewa national Forest in north central Minnesota, and will assume that generally the results apply throughout the forested area of the Lake States. Other speakers will supplement my somewhat generalized discussion with more specific data.

IMPOUNDMENT OBJECTIVES--WHY DO WE BUILD THEM?

The objectives of altering wetland habitat with low-head dams have gone through an evolutionary process. Objectives today are more complex than those of 20 years ago. Clearly, increasing waterfowl production and duck hunting opportunities was the primary objective during the early years. Drainage of prairie wetlands was destroying significant acreages of waterfowl production habitat. It was reasoned that some of this loss could be mitigated by improving the more secure wetlands in forested areas where there was also a substantial amount of public land (Hawkins and Green 1966). This continues to be a valid objective for creating impoundments, especially where agency missions and funding sources respond to the consumptive uses of hunting and trapping.

During the seventies when the term "nongame" wildlife was spawned, managers were seriously considering the effects of habitat manipulation on the nonconsumptive aspects of wildlife. Words such as "diversity," "communities," "species richness," and "holistic" appeared in the vocabularies of wildlife managers. The waterfowl production and harvest objective of wetland improvement, though still an important part of the whole, was considered within a broader context of community relationships among all vertebrates.

Special-status species, other than game and fur, were being recognized; these included "threatened" and "endangered," "sensitive" and "management indicator" species.

In the National Forest System, diversity itself is a wildlife management objective, mandated by the National Forest Management Act (Siderits and Radtke 1977). The purpose of the diversity objective is to achieve stability in the ecological sense, and to provide both game and nongame recreational opportunities. The simplest measure of diversity is the number of species, termed species richness (MacArthur 1965). I will use this term throughout the paper.

The objectives for creating wildlife impoundments, therefore, are: (1) enhancement of diversity, encompassing the entire range of species; and (2) improvement of habitat for selected groups of species having a special status.

PERFORMANCE--DO IMPOUNDMENTS IMPROVE UPON NATURAL WETLANDS?

Having defined in a general sense what managers are trying to accomplish with an impoundment, I can now compare natural aquatic communities to the habitat produced by low-head dams in terms of their ability to reach objectives.

All Wetlands Are Not Equal

Each wetland community has a unique assemblage of vertebrate fauna. Some are more diverse than others; some are more important for game and fur species. Some are used primarily for feeding, while others are more important as breeding habitats. Some are relatively more important to birds; others are more important to mammals or reptiles and amphibians. The next step is to sort all of this out.

Wildlife Habitat Association Data Base

A database assembled for the Chippewa National Forest provides a systematic way to predict the effects of habitat alteration on all vertebrates, excluding fish (Mathisen 1980). It also facilitates the ranking and assessment of habitat types (called communities) in terms of species richness and other parameters.

The database consists of nine interrelated elements that correlate 310 vertebrate species with habitat, season of use and status. Twenty-four communities, described by Niemi and Pfanmuller (1979), were modified to accommodate the vertebrates on the Chippewa. They reflect a combination of vegetation, successional stage, and structure. Eight of these are aquatic communities.

Each species was categorized by the communities utilized for feeding and/or breeding. Because most species are oriented to more than one community, an attempt was made to assign one of these communities as particularly important. This was termed the "critical community" for a species. It was impossible to assign a critical community to the more ubiquitous species.

Eight categories were used to relate special habitat requirements to each species, (man-made structures, edge, decaying log, snags, riparian areas, mast and banks or bare ground). Each species was also categorized for season of use (migration, summer, winter, permanent resident) and status (threatened, endangered, sensitive, game/fur, indicator). The data were entered on an IBM OS/6 Word Processor for storage and manipulation, and to facilitate updating.

Species Associated With Aquatic communities

The eight aquatic communities will be the framework for assessing performance and predicting the effects of altering wetlands by impoundment. Communities described below are given a descriptive name, and the appropriate classification according to the National Wetland Inventory System (Cowardin *et al.* 1979), is shown parenthetically.

Lake (Lacustrine/Limnetic Permanently Flooded)--This habitat is the open water of lakes at least 10 acres in size. Included are unvegetated beaches and mud flats, but no areas of emergent vegetation.

Woodland Pond (Palustrine/Aquatic Bed/Permanently Flooded)--This community is similar to a lake, except it is less than 10 acres in size and maximum depth is less than 6 feet.

Streams and Rivers (Riverine/Lower Perennial)--This community consists of open, moving water. It does not include associated areas of emergent vegetation.

Emergent Nonpersistent (Palustrine/Emergent/Nonpersistent/Intermittently Exposed or Lacustrine/Littoral/Emergent/Nonpersistent)--This community is a wetland or the littoral zone of a lake with emerging vegetation that does not persist due to die-back or ice action (e.g., wild rice, bulrush). If associated with a river or stream, it is in the Riverine System.

Emergent Persistent (Palustrine/Emergent/Persistent/Seasonally Flooded or Semipermanently Flooded)--This has emergent vegetation that persists through the winter (e.g., cattails, reed). There is no Emergent Persistent community associated with lakes and rivers in the NWI System.

Sedge Meadow (Palustrine/Emergent/Persistent/Saturated or Seasonally Flooded)--A type of Emergent Persistent Community, this was listed separate because of its importance on the Chippewa National Forest. It is a densely vegetated wetland of sedges, grasses and annuals; sometimes a floating mat.

Shrub Swamp (Palustrine/Scrub-Shrub/Broadleaved Deciduous)--This wetland is dominated by woody vegetation, usually alder and/or willow. Trees are absent.

Open Heath Bog (Palustrine/Scrub-Shrub/Broadleaved Evergreen/Saturated)--This wetland is characterized by a bed of sphagnum moss (often a floating mat) with leatherleaf, Labrador tea and other heaths dominating. There are very few trees (if present they are stunted) or broad-leaved shrubs.

Table 1 shows the number of species occurring on the Chippewa National Forest associated with these eight communities for feeding and/or breeding. Table 2 shows the number of special status species having an orientation to these communities. From these data, we can conclude that:

1. The shrub swamp community provides suitable

Table 1.--*Number of species that feed and/or breed in eight aquatic communities, Chippewa National Forest*

Community	Feeding	Breeding	Both	Total
Shrub swamp	49	2	42	93
Lake	66	-	5	71
Sedge meadow	40	4	23	67
Emergent persistent	35	4	25	64
Emergent nonpersistent	42	5	14	61
Pond	49	4	6	59
Heath bog	32	2	24	58
Stream and river	50	2	5	57

habitat for the most species, especially for breeding purposes.

2. While the open water of lakes ranks second in species richness, the use is almost entirely for feeding.
3. The heath bog and stream have the lowest level of species richness among the 8 communities.
4. Special-status species, as a group, are highly oriented to the emergent persistent and emergent nonpersistent communities. These are largely game/fur species.
5. Sensitive species are particularly associated with the heath bog, sedge meadow, and open water of lakes and ponds.

Organized information on the relative importance of aquatic communities to vertebrates is provided by the database and can now be used to assess the effects of altering these communities and to address the question: Does an impoundment provide suitable habitat for more species than does its natural predecessor?

Table 2.--*Number of special status species with an orientation to eight aquatic communities, Chippewa National Forest*

Community	Game/ fur	Thrt/ endg	Sensitive	Total
Emergent nonpersistent	27	-	3	30
Emergent persistent	26	1	3	30
Lake	18	2	6	26
Sedge meadow	18	1	6	25
Shrub swamp	19	2	1	22
Pond	15		6	21
Stream and river	15	2	4	21
Heath bog	7	1	7	15

Effects of Altering Aquatic Communities With Low-Head Dams

Building a wildlife impoundment usually results in the conversion of one community to a combination of other, presumably more valuable communities. The database can be used to assess these effects in terms of impoundment objectives.

Impoundment sites are generally selected to convert relatively monotypic wetlands, usually sedge meadows, shrub swamps, and occasionally lowland deciduous forests to complexes consisting of ponds, emergent persistent, emergent nonpersistent, and shrub swamp communities. Numerous combinations of amount and varieties of communities are possible within an impoundment. Biologists have always maintained that the more the variety and complexity, the greater will be productivity and species richness--but, how much greater is it? I can deal with the question by using the database to assess four typical conversions.

Case 1.--*Sedge meadow converted to an impoundment consisting of pond, emergent persistent, and emergent nonpersistent communities.*

Table 3 displays existing habitat suitability by class of vertebrate and type of use for the sedge meadow before flooding, and for the impoundment after flooding. Table 4 shows the effects of this conversion on special status species. From these the following conclusions can be reached:

1. Potential species richness is increased by 25 species, or 3 percent.
2. Habitat suitability for birds is particularly enhanced in the impoundment, increasing by 19 species, or 42 percent.
3. Habitat suitability for mammals remains about the same, although fewer breed in the impoundment.

Table 3.--*The effect of converting a sedge meadow to a comlex of pond, emergent nonpersistent and emergent persistent on species richness*

(In number of species)

	Before				After			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	27	3	15	45	48	-	16	64
Mammals	6	1	8	15	11	-	3	14
Herps	7	-	-	7	3	5	6	14
Total	40	4	23	67	62	5	25	92

Table 4.--*The effect of converting sedge meadow to a complex of pond, emergent nonpersistent, and emergent persistent on special-status species*

(In number of species)

	Before				After			
	Game /fur	Sens.	T/E	Total	Game /fur	Sens.	T/E	Total
Birds	12	4	-	16	23	5	1	29
Mammals	6	2	1	9	6	2	-	8
Herps	-	-	-	-	1	-	-	1
Total	18	6	1	25	30	7	1	38

4. Habitat suitability for reptiles and amphibians increases by 7, or 50 percent.
5. Habitat suitability for game/fur species increases by 66 percent, while the effect on other special-status species remains essentially unchanged.

Species composition within the impoundment will change considerably from that in the sedge meadow. Vertebrates using the sedge meadow as a critical habitat (such as marsh hawks, yellow rails and snowy owls) will be displaced. The new community complex will be suitable for a variety of waterfowl, gulls, loons, kingfishers, water shrews, and chorus frogs, to name a few.

Case 2.--*Shrub swamp converted to an impoundment consisting of pond, emergent persistent, and emergent nonpersistent communities.*

Flooding a shrub swamp often entails the choice of retaining a portion, usually on the periphery, in the original shrub swamp community in addition to open water and other aquatic communities. This case assumes the shrub swamp is eliminated; case 3 assumes that some shrub swamp is retained.

Table 5 compares species associations before and after flooding. Table 6 does the same for special-status

Table 5.--*The effect of converting a shrub swamp to a complex of pond, emergent nonpersistent and emergent persistent on species richness*

(In number of species)

	Before				After			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	34	2	26	62	48	-	16	64
Mammals	9	-	11	20	11	-	3	14
Herps	6	-	5	11	3	5	6	14
Total	49	2	42	93	62	5	25	92

Table 6.--*Effect of converting a shrub swamp to a complex of pond, emergent nonpersistent, and emergent persistent on special-status species*

(In number of species)

	Before				After			
	Game /fur	Sens.	T/E	Total	Game /fur	Sens.	T/E	Total
Birds	10	1	-	11	23	5	1	29
Mammals	9	1	1	11	6	2	-	8
Herps	-	-	-	0	1	-	-	1
Total	19	2	1	22	30	7	1	38

species. From these data we can conclude that:

1. Potential species richness remains about the same.
2. The habitat is suitable for fewer breeding species in the impoundment than in the original shrub swamp.
3. The impoundment produces a significant shift to game/fur species (58 percent increase), and is also more suitable for threatened, endangered, and sensitive species.

The mix of species is drastically different after flooding. Many species, especially birds associated with the shrub swamp, are displaced because of the transitional nature of this community. Species such as cuckoos, ruffed grouse, and various woodpeckers, warblers, and sparrows will be displaced. But many waterfowl, rails and shorebirds--absent in the original shrub swamp--will find the impoundment habitat suitable.

Case 3.--*Shrub swamp converted to an impoundment consisting of pond, emergent persistent, and emergent nonpersistent communities with some shrub swamp remaining.*

Tables 7 and 8 display the effects of an impoundment having the potential to retain a portion of the

Table 7.--*The effect of converting a shrub swamp to a complex of pond, emergent nonpersistent and emergent persistent and shrub swamp on species richness*

(In number of species)

	Before				After			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	34	2	26	62	69	-	42	111
Mammals	9	-	11	20	15	-	13	28
Herps	6	-	5	11	3	1	11	15
Total	49	2	42	93	87	1	66	154

Table 8.--*Effect of converting a shrub swamp to a complex of pond, emergent nonpersistent, and emergent persistent and shrub swamp on special-status species*

(In number of species)

	Before				After			
	Game /fur	Sens.	T/E	Total	Game /fur	Sens.	T/E	Total
Birds	10	1	-	11	27	5	1	33
Mammals	9	1	1	11	11	3	1	15
Herps	-	-	-	0	1	-	-	1
Total	19	2	1	22	39	8	2	49

area in the shrub swamp community, and if water level management strategy provides for its maintenance. We can conclude that:

1. Species richness increases from 93 to 154, or 66 percent.
2. The habitat is suitable for 50 percent more species of breeding birds.
3. The habitat is suitable for 95 percent more game/fur species, almost double that of the original community.
4. There are 67 percent more species accommodated than in an impoundment with no shrub swamp component.

Case 4.--*Lowland deciduous woodland converted to an impoundment consisting of pond emergent persistent and emergent nonpersistent communities.*

Although less common than other conversions, a wooded community is occasionally involved in an impoundment project. From tables 9 and 10 we can conclude that:

1. Species richness is increased by 33 percent, mostly for feeding purposes.

Table 9.--*The effect of converting a mature lowland deciduous community to a complex of pond, emergent nonpersistent and emergent persistent on species richness*

(In number of species)

	Before				After			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	6	5	29	40	48	-	16	64
Mammals	-	-	21	21	11	-	3	14
Herps	7	-	1	8	3	5	6	14
Total	13	5	51	69	62	5	25	92

Table 10.--*Effect of converting a mature lowland deciduous community to a complex of pond, emergent nonpersistent, and emergent persistent on special-status species*

(In number of species)

	Before				After			
	Game /fur	Sens.	T/E	Total	Game /fur	Sens.	T/E	Total
Birds	5	1	-	6	23	5	1	29
Mammals	6	2	1	9	6	2	-	8
Herps	-	-	-	0	1	-	-	1
Total	11	3	1	15	30	7	1	38

2. The habitat is suitable for more special-status species, especially game and fur species, increasing 153 percent in the impoundment.
3. The number of mammals that use the habitat for breeding is significantly reduced (from 21 to 3 species).

The changes in this case are the most dramatic in terms of species composition. A forested community supports very few wetland-oriented species and there is very little commonality among species in the deciduous woodland and the impoundment.

The Role of Lakes and Rivers

Lakes play an important role as wildlife habitat in the north central States. Our database shows 83 species with an orientation to lake and/or river habitat, primarily for feeding (table 1). Lakes are considered to be critical communities for 38 species. Among these are popular species such as common loons, bald eagles, and ospreys. Does the presence of lakes and rivers, therefore, preclude or diminish the need for constructing impoundments?

Just as all wetlands are not equal, neither are all lakes and rivers equal. Some are relatively monotonous open bodies of water with little emergent vegetation, while others have well-developed littoral zones of emergent nonpersistent communities. Lacustrine habitats do not have emergent persistent associations due to the effects of ice.

Table 11 shows the species relationships in a lake community with little or no littoral development, compared to one with a well-developed emergent nonpersistent community. Emergent vegetation provides suitable habitat for 36 additional species, mostly for breeding. A comparison of this community arrangement with a typical impoundment is shown in tables 12 and 13. Species richness and habitat suitability for

Table 11.--*Species associated with a lake community compared to a lake with an emergent nonpersistent component*

(In number of species)

	Lake only				Lake + emerg. nonpersistent			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	56	-	4	60	69	-	9	78
Mammals	8	-	-	8	11	-	3	14
Herps	2	-	1	3	3	5	7	15
Total	66	-	5	71	83	5	19	107

special-status species are very similar between the two, with the impoundment having a slight advantage for breeding. When the shrub swamp component is available in the impoundment, more species find it more suitable than the lake.

A factor to consider when comparing lakes to impoundments is scale. While there may be huge acreages of lake habitat, the portion used by most species is a narrow band of emergent vegetation interfaced with open water. Conversely, a typical impoundment or natural wetland complex is more efficiently utilized due to the interspersion and juxtaposition of its components.

Lakes and rivers are similar to impoundments in many respects, but notable differences make comparisons difficult. In any case they cannot be compared acre for acre.

The Riparian Effect

Of the 310 vertebrates occurring on the Chippewa National Forest, 115 or 37 percent are associated with riparian habitat. This important and productive zone where water and upland come together is inherent in all communities with surface water (Thomas *et al.* 1979).

Table 12.--*Species richness in a lake with an emergent nonpersistent component compared to a typical impoundment (pond, emergent nonpersistent and emergent persistent)*

(In number of species)

	Lake + emerg. nonpersistent				Impoundment			
	Feeds	Breeds	Both	Total	Feeds	Breeds	Both	Total
Birds	69	-	9	78	48	-	16	64
Mammals	11	-	3	14	11	-	3	14
Herps	3	5	7	15	3	5	6	14
Total	83	5	19	107	62	5	25	92

Table 13.--*Special-status species associated with a lake with emergent nonpersistent component compared to a typical impoundment (pond, emergent nonpersistent and emergent persistent)*

(In number of species)

	Lake + Emerg. Nonpersistent				Impoundment			
	Game /fur	Sens.	T/E	Total	Game /fur	Sens.	T/E	Total
Birds	27	5	2	34	23	5	1	29
Mammals	6	2	-	8	6	2	-	8
Herps	1	-	-	1	1	-	-	1
Total	34	7	2	43	30	7	1	38

The effect on wildlife, therefore, of producing surface water in a wetland where none existed previously, includes riparian species that are not directly associated with aquatic habitats. The number of upland species affected at any given site depends on the type of upland community(ies) adjacent to the impoundment. The database indicates that 17 additional, upland vertebrates potentially benefit from the creation of riparian habitat (8 birds, 7 mammals, 2 reptiles). Among them are pileated woodpeckers, barred owls, flying squirrels, and garter snakes.

SUPPLY--IS THERE A SHORTAGE OF NATURAL AQUATIC COMMUNITIES?

The next step is to determine if enough wetland habitat similar to impoundments is available so that creating more may be precluded.

The existing wetland inventory on the Chippewa is based on Shaw and Fredine (1956) and is similar to the community classification in the database. Unfortunately, we have no reliable inventory data on emergent communities associated with lakes and rivers.

Table 14 shows the number of acres and the proportions of various communities based on our inventory of 1965. I have combined the shallow marsh and deep marsh types, considering that these are analogous to the emergent communities used in the database. These types are also similar to impoundment habitat.

"Impoundment-like" habitat, exclusive of lakes and rivers, accounts for approximately 7.5 percent of the

Table 14.--*Community composition, Chippewa National Forest*

Community type	Acres	Percent
	Number	
Lake (limnetic zone)	319,500	60.9
River and stream	2,876	0.5
Shrub swamp	86,116	16.5
Sedge meadow	59,458	11.4
Emergent[1]		
Wetland	13,067	2.5
Lake	28,400 (est.)	5.4
River	700 (est.)	0.2
Heath bog	11,609	2.2
Pond	2,217	0.4
Total	523,943	100.0

[1]Includes persistent and nonpersistent.

total wetland resource on the forest. Sedge meadows and shrub swamps, the communities most often targeted for conversion, account for 84.5 percent of the total wetland resource. Therefore, impoundment-like habitat is in relatively short supply and constructing impoundments to convert abundant sedge meadow and shrub swamp communities is justified in light of the performance of impoundments in meeting objectives.

Although there is no inventory of emergent communities associated with lakes and rivers, there are 347,888 acres of lake within the forest with 1,775 miles of shoreline, and about 600 miles of streams and rivers, totaling 3,576 acres.

If an estimated 20 percent of lake shoreline is vegetated with emergent communities (an educated guess) for an average distance of ⅛ mile from shore, an additional 28,400 acres of habitat similar to impoundments is provided. If 20 percent of the streams and rivers consists of emergent communities (a rough estimate, to be sure) another 700 acres of impoundment-like habitat is available. Even with these proportions, impoundment-like habitat is only 9.1 percent of the total aquatic resource, while the shrub swamp and sedge meadow total 27.9 percent.

ECONOMICS--CAN WE MEASURE COST-EFFECTIVENESS?

What about the appropriateness of constructing impoundments in terms of wildlife supply/demand, and the economics of cost-effectiveness?

In the past, we have attempted to measure these elusive factors, but studies lacked credibility and usually frustrated the biologists trying to apply economic theory that was barely understood.

I believe we are now on the threshold of better understanding. These economic measurements for impoundments are now available in draft form on the Chippewa National Forest. They will soon be published as part of the Forest Land Management Plan. The preliminary analysis, based on literature review and professional assumptions, indicate that demand for waterfowl, fur-bearers and nongame species will increase through 2030. The cost/benefit analysis, based on mandatory standards and methods, indicate a positive relationship for wildlife impoundment construction.

SUMMARY AND CONCLUSION

I have defined two broad objectives for creating impoundments, one dealing with diversity as an ecological concept, and the other relating to the welfare and production of particular groups of species, including game/fur, threatened/endangered and sensitive. By converting natural wetlands to impoundments, these objectives can be realized.

Species associated with eight aquatic communities were examined in terms of the two objectives. Then, results of converting some of these to impoundment complexes were examined. Converting monotypic wetlands to various combinations of aquatic communities by constructing low-head dams, produces variable effects on vertebrate species richness and species composition, depending on the communities involved. Animal diversity can be significantly increased, and the effect on game/fur and other special-status species is highly positive.

Lakes with well-developed littoral areas of emergent vegetation are similar to impoundment habitat in terms of species suitability, except in cases where the shrub swamp component is part of the impoundment complex. In this case, impoundment performance exceeds that of lake habitat.

Unlike natural wetlands and lakes, most impoundments have a capacity to sustain high-level productivity through water level manipulation to enhance characteristics such as shrub swamp borders and nutrient richness (Knighton 1982).

The wetland inventory of the Chippewa National Forest was examined to determine whether enough "impoundment-like' natural wetlands exist to preclude creating more with dams. Only 7.5 percent of the wetland resource on the forest is analogous to impoundment habitat in terms of vertebrate species suit-

ability; while 84.5 percent is comprised of the types most often targeted for conversion. Impoundments, therefore, serve to provide a more diverse community over the area, meeting the objectives of diversity and ensuring the habitat needs of special-status species are met.

Preliminary economic analyses indicate that the demand for waterfowl, fur-bearers, and nongame species will increase in the next half century. Economic measurements are not available in draft form for the Chippewa National Forest.

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SELECTION OF WATER IMPOUNDMENT SITES IN THE LAKE STATES

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Water can be impounded to provide habitat suitable for waterfowl, fur bearers, amphibians, reptiles, songbirds, and raptors. Selecting these sites requires considering several factors including: an inventory of wetlands, a topographic survey of potential sites to predict normal pool size and the final interspersion of water and vegetation, design criteria for low flows that are sufficient to maintain water levels throughout the summer, and design criteria for high flows which the dam must retain or pass. This chapter will focus on factors preceding dam design and list a number of considerations for prioritizing construction schedules.

WETLAND INVENTORIES

Throughout the forested, northern Lake States, water impoundment sites are mostly freshwater wetlands (specific conductance < 800 micromhos). These will have at least intermittent streams leaving them, occur at the beginning of perennial streams, or along the sides of a perennial stream. Impoundment proposals may be for a single site or for many sites derived from the evaluation of a wetland inventory.

Wetland inventories for any administrative unit are made to locate and classify areas according to management objectives. The objectives may include timber potential or stand establishment needs, drainage suitability, energy potential (on organic soils), and wildlife management potential aimed at fish, fur bearers, and waterfowl. Several wetland classification systems suitable for wildlife management potential include: Shaw and Fredine (1956) (Circular 39), Stewart and Kantrud (1971), Golet and Larson (1974), and Cowardin *et al.* (1979). The latter compares classification criteria among the four systems and is an excellent reference to consult first in planning an inventory. The few kinds of wetlands most important for impounding water for wildlife are listed in table 1 for two of the systems; many other classes are available for inventories with broader management objectives. The theory of inventorying wetlands will be discussed using the terminology of Circular 39.

Type 1 wetlands (seasonally flooded basins) are not included because they are difficult to inventory from a single set of aerial photos, particularly in forested areas (they are numerous in the Prairie Region, much less so in the Forested Region, but provide breeding pair habitat). Type 2 wetlands (sedge meadows) are of little importance to waterfowl because of little or no open water but may be used for nesting. Type 3 wetlands (shallow marshes) are extensively used by breeding pairs but frequently dry up before brood-rearing is completed. Type 4 wetlands (deep freshwater marshes) are the best breeding habitat and also serve as feeding places for migratory waterfowl. Type 5 wetlands (open water) are generally classified as lakes if their area exceeds 10 acres (4 ha). Emergent vegetation around the edge is used by broods. They do not require impounding unless adjacent wetlands can add substantial areas of interspersed water and vegetation by raising the lake level. Type 6 wetlands (shrub swamps) have low waterfowl use unless open water areas are well interspersed. Type 2, 3, and 6 wetlands can be converted into areas more suitable for waterfowl by impounding water and shifting their classification to type 4 (deep freshwater marshes).

Steps in the wetland inventory process follow.

1. Define the basic inventory unit.
   The basic inventory unit is broadly defined by administrative boundaries and should include outlines of other ownerships where potentially impounded wetlands may be precluded. Examples of a basic inventory unit include: a county, a ranger district, a refuge, etc. For large areas inventory units can be combined, such as combining ranger districts to cover an entire state or national forest, county, etc.
2. Obtain vertical aerial photos and USGS topographic maps that cover the entire inventory unit. Standard resource photography (9 × 9 inch in a variety of films) can be obtained at a scale of 1:24,000, which matches the USGS 7.5 minute series orthophoto map (topographic). However, ex-

Table 1.--*Most useful wetland classification units for areas suited to water-impoundments for wildlife (impounding types 2, 3, and 6 creates a type 4 wetland, most suitable for waterfowl production)*

Circular 39 type (Shaw and Fredine 1956)	Classification of wetlands and deepwater habitats (Cowardin 1979)		
	Classes	Water Regimes	Water chemistry
Type 2-Inland fresh meadows. Largely sedge meadows in the Lake States. They are without standing water during most of the growing season, but the soils are water logged within a few inches of the surface.	Emergent Wetland	Saturated	Fresh
Type 3-Inland shallow fresh marshes. In most years they retain water until mid-summer, but frequently dry up before brood-rearing is complete. Water is generally less than 6 inches (15 cm) deep.	Emergent wetland	Saturated	Fresh
Type 4-Inland deep fresh marshes. These are covered with water 6 to 36 inches (90 cm) or more during the growing season	Emergent wetland Aquatic	Permanently flooded Intermittently exposed Semipermanently flooded	Fresh
Type 6-Shrub swamps. These are usually waterlogged during the growing season and often covered with as much as 6 inches (15 cm) of water.	Scrub-shrub wetland	All nontidal regimes except Permanently floods	Fresh

isting photography at 1:15,840 can also be used. The minimum wetland acreage that can be mapped at these two scales is 6 acres (2.5 ha) and 2.5 acres (1 ha) respectively. For small units, small format (35 or 70 mm) aerial photography can substitute for or supplement the 9 × 9 standard (Meyer 1982).

3. Use the 9 × 9 photo with an acetate overlay to delineate and identify wetlands. You will be able to identify wetland type in most instances from the photo; use the orthophotomap for general location and drainage patterns.
4. To assist in dam siting, plan to make notations of both active and abandoned beaver dams, and primary wildrice producing areas that may help in prioritizing impoundment sites.
5. Arrange the air photos in either north-south or east-west flight strips. Start with the photo in the northeast corner of the basic inventory unit and work south to the southern border, then begin with the north photo of the next strip to the west and continue with this pattern until the next unit is completed.
6. Place an acetate overlay on each photo. Outline each wetland and indicate inflowing and exit streams with an arrow. Determine area with a dot grid. Label each wetland with three numbers (ex: 35-15-2). The first number is the individual wetland number starting with 1 and continuing throughout the entire inventory. The second number is area (acres or hectares). The third number is wetland type number (such as 2 for sedge meadow). If the type cannot be determined from the photo, underline the first two numbers to indicate that this wetland must be field-checked.
7. Outline other ownerships, mark beaver dams, note primary wild rice producing areas, outline lakes, and identify the overlay.
8. Identify the photo overlay by strip number and photo number in the strip in the upper right-hand corner. List township and range in the upper left corner of the overlay. Draw in and identify section corners. See figure 1 for an example overlay.
9. Record overlay information with the headings: wetland number, area, type, photo strip number, photo number, township, range, section, field checking needed, beaver dams, and comments on sites apparently suitable for impounding, including land acquisition needed, or cooperative ventures among land owners required.

The final product of a wetland inventory is a summary document for the basic inventory unit containing:

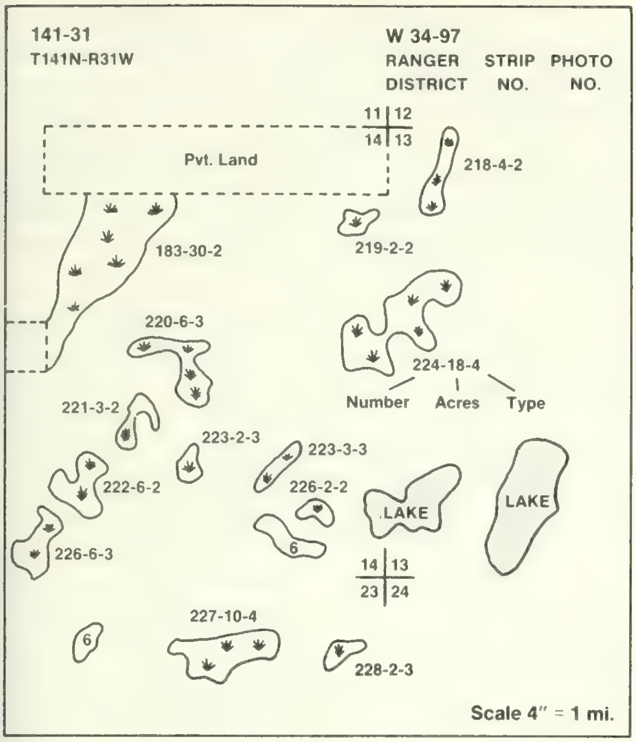

Figure 1.--*Sample Aerial Photo Overlay.*

1. Total number and areas of wetlands.
2. Relative abundance of wetland types.
3. Distribution of types by size classes.
4. Sites where there is impoundment potential.

BUILDING THE BEST POTENTIAL IMPOUNDMENT SITES FIRST

Shallow water impoundments are constructed to improve wetland habitat productivity. A host of things, (some of which will be explained in detail later) must be considered in choosing an area for dam construction. The following is a check list beginning with conditions that should rule out impoundment construction before detailed site work is done.

Do not construct an impoundment:

1. Where existing surface water has a specific conductance less than 25 micromhos, or where the watershed area to surface water area ratios are low (explained later).
2. That will destroy endangered plants.
3. On a stream designated as potable water or a trout stream by State agencies. Trout streams should not exceed 21° C (70° F) at summer maxima and should have gradients favored by viable brown trout populations. These gradients vary with stream width: 7-8 percent slope in streams up to 10 meters (30 feet) wide, 6-7 percent (10-23 meters wide), 5-6 percent (23-60 meters wide), 4.7-5 percent (60-90 meters wide), (Allen 1969). If both temperature and slope conditions exist the area should not be considered for impoundment. In very cold streams that do not exceed 10° C (50° F) impounding results in better fish growth (Waters 1977).
4. If a major spawning run is blocked.
5. If a significant amount of winter deer-yard cover is flooded.
6. If nearby lakes or roads will be flooded.

Give high priority to potential impoundment sites:

7. Where the development cost per acre is lowest. Limit flooded areas to 25 acres and more.
8. Where new road construction to the site is minimal.
9. Where existing roadways can be incorporated in the dam design.
10. Where narrow upland constrictions mean a shorter dam length.
11. Where new impoundments are within 1.6 kilometers (one mile) of other wetland types including lakes. This will encompass the minimum puddle duck home range for breeding pairs and broods.
12. Where land ownership is under one or two agencies or one individual.
13. Where islands and irregular shoreline exist.
14. Where 30 to 70 percent of the normal pool area will be less than 3 feet deep.
14. Where floating mats will not break loose and clog spillways.

EVALUATING A POTENTIAL IMPOUNDMENT SITE

The following evaluation steps were developed in north central Minnesota and tested for consistency of application by observations in forested areas of Wisconsin and Michigan. The area of application is defined in kind by Cowardin *et al.* (1979) as fresh water wetlands (< 800 micromhos) within the Palustrine and Riverine systems. They are defined in area by Bailey's (1976) Ecoregions encompassing the four sections of the Laurentian Mixed Forest within the warm continental division of the Humid Temperate domain. This includes the northeastern one-third of Minnesota, the northern half of Wisconsin, the northern two-thirds of Michigan, New York, Vermont, New Hampshire, Maine and adjacent areas of southern Canada exclusive of maritime zones. Some general principles will apply in other areas, but water quality guides need local derivation outside of these areas.

Topograhic Survey

A topographic survey at 1-foot contour intervals is required to calculate flood storage volume above a selected normal pool[1] elevation. (Note: consistently set the level rod in the bottom of a hollow to minimize elevation variation in hummock-hollow surfaces). In addition, a profile of acres flooded at various 1-foot depths can be used to calculate total normal pool area, area of open water, area of emergent vegetation, and the ratio of emergent vegetation to open water. A tabulation of this information will show where total impoundment area can be maximized while keeping the ratio of vegetation to water area at 30 to 50 percent. (See appendix A for details). These considerations must be made within the constraints of land ownership and other topographic controls. Having selected a normal pool elevation, there is still no guarantee that the impoundment site will hold water throughout the summer.

Avoiding an impoundment site that will not hold water or be of marginal use for waterfowl production requires the consideration or measurement of four additional things: area geology, watershed boundary, impoundment soils, and water supply. If three of them say "yes" (that is, construct the impoundment) and one says "no," a mistake in measurement or interpretation was probably made in at least one of the three positive areas. If all four things say "yes," then you can assume the site will have adequate water. These four areas of consideration follow; one leading into the next. If you get to the end and still affirm that the site will collect and hold water, proceed with designing a dam.

Geologic History

First, you should have a basic understanding of the glacial history of the administrative unit you are selecting sites from. This is available from soil surveys and texts or papers on pleistocene geology within your State. Become familiar with outwash plains, glacial lake beds, ground moraines, end moraines, and buried sand and gravel aquifers. This will give a general idea of the porosity of earth materials at the impoundment site and its surface and underground watersheds.

In the back of your mind, you should be asking the questions: How will water get to and be sustained at this potential site? Are there porous materials that act as a water conduit to the site? Where is the regional water table? Are there rock types that may yield a unique water quality (specific conductance)? Will bottom materials hold water or will they leak? Will fluctuations of 2 or 3 feet in the regional water table affect this site?

Obviously this area of consideration is based on experienced interpretation of a geologic setting. Get to know your pleistocene geology, and parts of the site evaluation puzzle will fit together with ease. Figure 2 depicts a typical geologic setting in north central Minnesota and the relation of several wetlands to the regional water table. Groundwater is high in specific conductance because of calcium dissolved from limestone fragments lying in a mixed horizon on top of deep bedrock. Specific conductance in wetlands indicates the size of surface drainage area or whether there is direct contact with the regional water table. With reference to specific conductance in the wetlands of figure 2, the 25 wetland has a small surface drainage basin, the 26-100 wetland has a large, surface water drainage basin, the 101-150 wetland has a mixture of surface and groundwater which may be dependent on the regional water table fluctuation, and the 151+ wetland has a strongly dominating groundwater flow.

Define the Watershed

Second, define the surface watershed from 7.5-minute series orthophoto maps (topographic). It is easy to make a mistake at this point. Do not use forest type maps, because the tendency in using type maps is to draw watershed boundaries around wetland types that are not in the immediate vicinity of the impoundment site. In the northern Lake States it is common for a portion of a watershed boundary to cut through a wetland. In other words, many peatlands straddle watershed boundaries. If you are in doubt, field check boundary wetlands for multiple drainage outlets and their direction of flow.

Once the boundary is delineated, determine watershed area by dot grid, planimeter, or paper cut-out weighing on an analytic balance. Record the area for later use.

Sample Impoundment Soils

Third, go to the impoundment site, select a spot near the stream channel, but above water, and auger to at least a depth of 5 feet. Record the depth, color and texture of horizons using gross "thumb and forefinger" estimates of texture. Also record the reaction of each

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[1] *The "normal pool" is the area of water achieved by flooding to the top of the last stop log. It occurs at the design elevation for a stable water-level. Higher pools will occur during temporary flood storage and lower pools will occur during designed drawdowns or natural drawdown when evaporation exceeds water supply.*

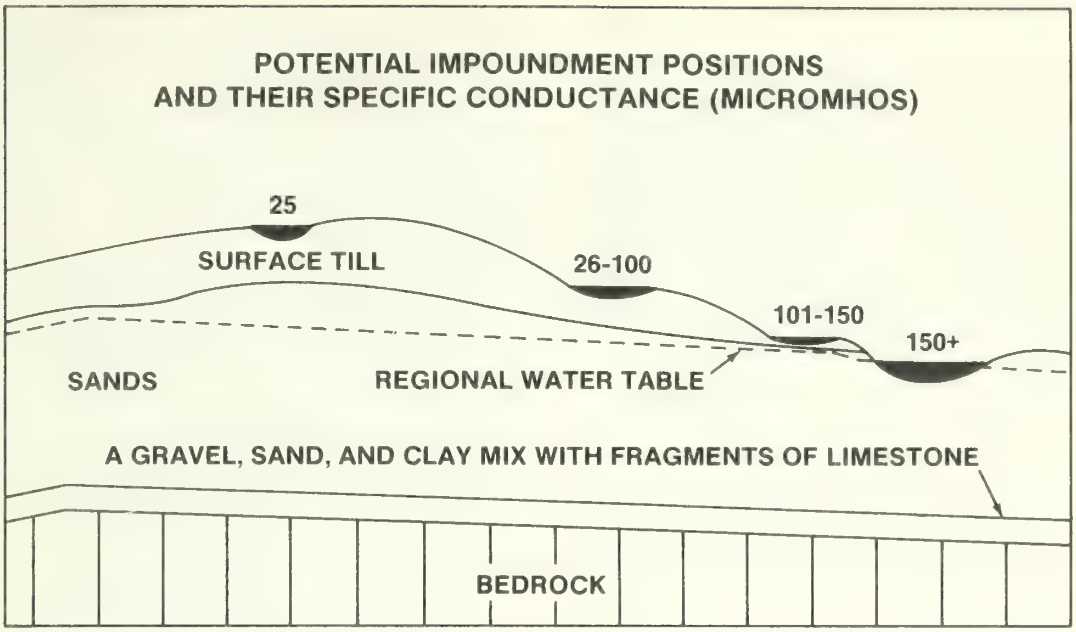

Figure 2.--*A typical geologic setting for wetlands in north central Minnesota. Water supply to wetlands can be increased if the wetland water table is the same as the regional water table.*

orizon to a 10 percent solution of HC1 as none, weak, ıoderate, or strong fizzing. Interpretation:

If organic horizons exceed 6 inches in depth and consist mostly of fibric materials (sample > ⅔ fibers), the organic mat will probably float after flooding.

This is based on the shallow rooting depth of wetland vegetation which is generally limited to 6 inches. Roots will extend into mineral soil through organic horizons less than six inches thick and serve to anchor the mat.

If thick fibric organic mats (0.5 to 3 feet) are found, you can predict where the mat will float by a survey of mat thickness. Productive impoundments can be made when mats float, but complete drawdown cycles will have little or no impact on mat vegetation in smaller impoundments (< 250 acres).

Maintenance surveys should pay particular attention to floating mats near the outlet. Large sections can break loose and clog emergency spillways and normal pool outlets.

Flooded peats (which are usually hemic or sapric in degree of decomposition and thus don't float) around the edges of large multi-purpose impoundments (1,000 acres plus in size) can be subject to severe erosion. The problem arises on areas receiving large spring runoff (> 1,000 cubic feet per second) if the impoundment is held at normal pool over winter. Then, if ice freezes deep enough to grab plant roots and the organic soil, spring flows will lift 6 inches or so of soil with the ice, pulverize it with wind-pushed ice, and flush it out in overflow. This annually deepens the shallow wildlife zone around an impoundment edge. In this situation erosion can be prevented by drawing water down during the winter. Begin drawdowns after 3 inches of ice have formed and drop the water-level to 2 to 3 feet. This provides for spring flood retention, but it also leaves a collapsed layer of 3 inches of ice on the top of the shallow areas with organic soil. These "mud flats" will melt out in the spring prior to the snowmelt peak flow. Starting drawdown with 3 inches of ice protects muskrat populations, otherwise drawdowns can start after the waterfowl season ends (Linde 1979).

2. Coarse sands to pebbles within the upper foot (may extend deeper).

a. Usually indicates a strong groundwater supply with a rapid delivery system (large pores) for spring snowmelt. At sites with a high risk dam, be certain that the watershed area is accurately defined so that emergency spillway design is adequate.

b. Water level control will be possible in most years. However, during very dry years the regional water table may drop below the bottom of the impoundment. Heavy rains and melt from deep snowpacks will be needed to bring the regional water table above the impoundment bottom. In other words, impoundments on deep sands have a very leaky bottom and water levels can be controlled only when the regional water table is higher than the dam bottom.

3. Horizons of *very fine* sand or silt or clay in the upper 5 feet.
   a. Impoundments with these kinds of bottoms will hold water. If medium to fine sand horizons occur above the clay, silt, or very fine sand horizons, there is a good chance for a groundwater supply. If not, this does not rule out the possibility of a groundwater supply since it may discharge to the surface up-stream of the impoundment site in localized "artesian well" areas.
4. Strongly calcareous soils in the upper foot (reacts strongly to 10 percent HC1).
   a. When calcareous soils occur within the upper foot it is necessary to rule out the use of specific conductance values in the water (described next) as an interpretation of groundwater supply. Assume that water supplies are of surface origin.
5. Strongly calcareous soils not present in the upper foot.
   a. Use specific conductance of the water to interpret water supply characteristics and suitability of the site for impoundment.

Measure Specific Conductance of the Water

Fourth, measure specific conductance of the water during June, July, August, September, or October. Avoid snowmelt periods and sampling within 2 or 3 days of a large storm (over 1 inch). Adjust measurements (micromhos/cm) to 25° C by dialing the temperature correction knob to the ambient water temperature, or by adding 2 percent per degree for each degree centigrade below 25° C or subtracting 2 percent per degree for each degree centigrade above 25°. Interpretation:

1. Reading ≤ 25: Guaranteed to have only a surface water supply of limited amount. Waters this low in conductance have traveled only short distances and were able to dissolve only minor amounts of mineral salts. Do not build an impoundment. Open water covering the estimated normal pool area will exist only during the spring of the year.
2. Readings 26-100: Surface water collected from the surrounding watershed predominates. Water level control may be possible in average to wet years if watershed area to impoundment area (normal pool) ratios equal or exceed table values (see table 2 to calculate specific values, or locate the potential site in figure 3 for general values). Water levels will be controlled by climate in dry years or if area ratios are less than table values.
3. Readings 101-150: Increasing values in this range indicate that the amount of groundwater mixing with surface water is increasing, but the ground-

Table 2.--*Acres of watershed per acre of impoundment surface needed to ensure a dependable water supply in the northern Lake States*[1]

Annual streamflow (Inches)	Summer and fall streamflow	Inches of open water evaporation				
		24	26	28	30	32
	Inches	*Acre of Watershed/acre of impoundment water at normal pool*				
2	0.7	34	37	40	43	46
4	1.8	13	14	16	17	18
6	3.0	8	9	9	10	11
8	4.1	6	6	7	7	8
10	5.2	5	5	5	6	6
12	6.4	4	4	4	5	5
14	7.5	3	3	4	4	4
16	8.7	3	3	3	3	4

[1]Table derived from the equation

$$Y = \frac{\text{Inches of open water evaporation}}{-.46 + .57\ (\text{inches of annual streamflow})}$$

Y = Surface watershed acres needed per acre of normal pool

This equation is shown with inches of annual streamflow because annual values are easiest to obtain. The ratios in fact are based on summer and fall streamflow because this is the time when water supply must match open water evaporation. Spring streamflow (April and May) fills the impoundment and overflows. It doesn't help to maintain the water at normal pool during the summer when evaporation is high. The denominator is a regression of summer and fall streamflow against annual streamflow from a small surface water area over a range of annual precipitation.

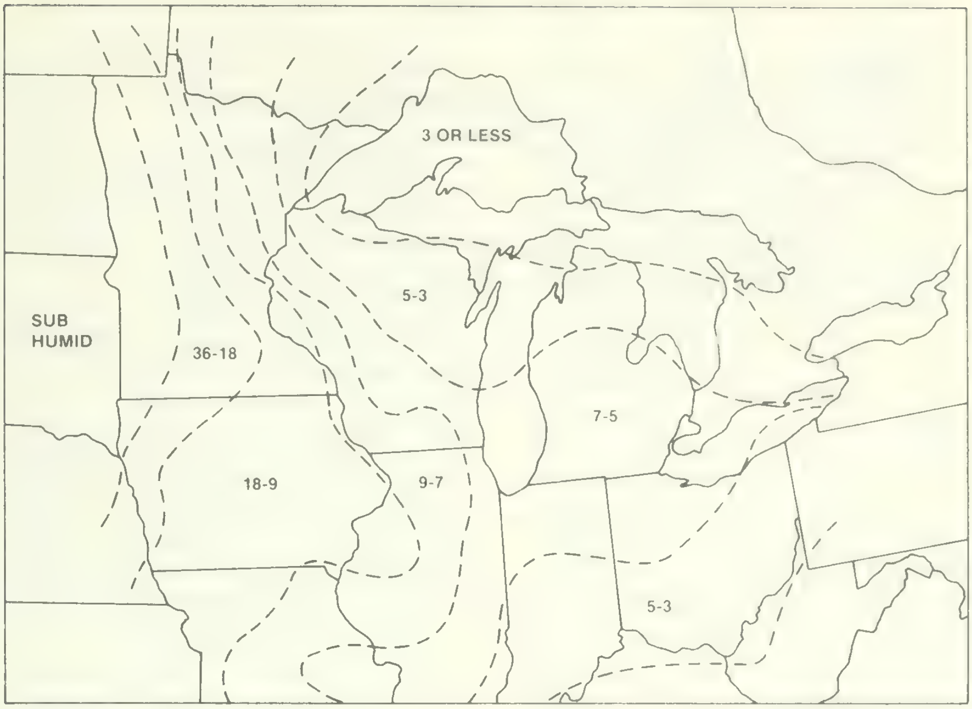

Figure 3.--*Zones of watershed-to-impoundment-area ratios sneeded to supply summer surface water runoff sufficient to maintain a normal pool water level.*

water does not dominate. Continue to rely on suitable watershed to impoundment area ratios.

4. Readings 151+: Groundwater dominates the supply to these impoundment sites. An adequate water supply is available during all but the most severe drought years. You can ignore area ratios. It may be that the surface watershed to impoundment area ratio is less than the table values; this means that the "ground-watershed" feeding the site is larger than the surface watershed.

If your knowledge in all four areas is compatible, then you're ready to consider dam construction and high-flow design criteria. If your knowledge is not compatible in all four areas, be suspect of your measurements and do them again.

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APPENDIX A

OPTIMIZING IMPOUNDMENT AREA

A topographic survey at 1-foot intervals can be used to calculate flood storage volume. In addition to giving a profile of acres flooded at incresing 1-foot depths, it can be used to tabulate water area information. This can be used to maximize water impoundment area while keeping the ratio of vegetation to water area at 30 to 50 percent (or close) within engineering constraints.

There are three considerations for impoundment construction. They are:

1. Maximize the flooded area to reduce the per acre cost.
2. Make sure there is sufficient freeboard (distance from normal pool to top of the dam) to temporarily store flood waters while most of the water passes through the emergency spillway; and make sure that road beds, other outlets, and adjacent other-owner property are not flooded.
3. Keeping water and vegetation in a reasonable mix (interspersion).

Figure 4 shows how a 1-foot contour interval map of an impoundment site can be used to tabulate and display area and cross section information. This technique should be used as a guide for establishing a normal pool elevation.

To begin with, information is tablulated by 3-foot increments. Why 3 feet? Because emergent vegetation will occupy the area at 0 to 3 feet below normal pool, and the area greater than 3 feet below normal pool will be for the most part open water. Other research recommends that the ratio of vegetation to water area be kept between 30 and 70 percent with 50 percent an optimum. Our studies show that emergents in stable water die out below 2 feet, but water levels in impoundments will naturally fluctuate 1-foot below normal pool so that a 3-foot increment typically reflects the emergent zone in most impoundments. If an area is likely to have a strong groundwater source and thus a stable water elevation, use a 2-foot increment. Where there are floating mats water depth is not critical. Interspersion will be determined by the total impoundment area and the mat area.

Figure 4 shows that open water area (63 percent) (emergent vegetation area 37 percent), and total impoundment area (88 acres) are optimized and maximized respectively at a normal pool elevation of 90 feet. Actual normal pool elevation was set at 89 feet to allow for sufficient free board and to protect adjacent road beds.

TOP ELEVATION (FT.)	3-FOOT INCREMENT (FT.)	AREA BETWEEN UPPER & LOWER INCREMENT ELEV. (ACRES)	AREA BELOW THE LOWER INCREMENT ELEV. (ACRES)	TOTAL AREA AT THE TOP ELEV. (ACRES)	ESTIMATED PERCENT OPEN WATER (%)
84	81-84	2.5	0.5	3.0	20
85	82-85	11.0	0.5	11.5	4
86	83-86	30.0	1.0	31.0	3
87	84-87	52.0	3.0	55.0	5
88	85-88	53.5	11.5	65.0	18
89	86-89	46.0	31.0	77.0	40
90	87-90	33.0	55.0	88.0	63

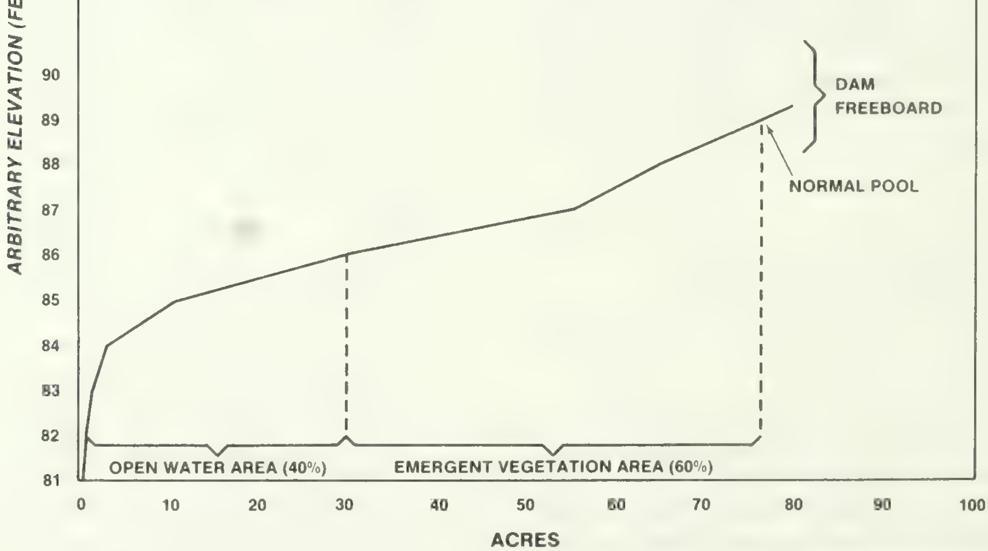

Figure 4.--*Topographic survey information (1-foot contour map) summarized for Bear Brook Impoundment on the Chippewa National Forest.*

VEGETATION MANAGEMENT IN WATER IMPOUNDMENTS: WATER-LEVEL CONTROL

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Within a physiographic region, the soil water regime s the most significant environmental factor deternining what plant species will occupy a particular site. There are a variety of factors that contribute to soil vater regimes, among them are topography, soil maerials, watershed size (Verry 1983), and climate. Varous measures of these factors were used to develop a key to opportunities for controlling water level for impoundments or impoundment sites according to their potential for wildlife habitat management. The key sets limits on prescriptions, determining what specific habitat management objectives are reasonable.

An existing impoundment or a potential impoundnent site is first examined for special conditions. These are deep organic soils, and the presence or potential development of extensive floating vegetation nats which, for the most part, resist control by waterevel manipulation. Impoundments without special onditions are then examined with respect to the difficulty expected in maintaining a water-level prescripion. The difficulty is a function of water supply lependability and the expense in time and equipment necessary to insure that the water-level is held at the prescribed level.

While selecting impoundment sites it is not necssarily wise to automatically rule out a site simply ecause precise water-level management prescriptions re unlikely to succeed. Even unmanageable impoundnents offer diversity to a management unit that may ot be achieved in any other way. It simply isn't praccal to expect all impoundments to mirror each other, r to be managed with some central image as the goal. f the goal is to maximize habitat diversity throughout management unit, then these impoundments may lso have their place.

When an impoundment is considered suitable for ater-level management, the prescription may require ther cyclic or non-cyclic drawdowns. Cyclic drawowns call for a repeating water-level regime that may equire 5 or more years to complete, but does not reuire a regular on-site evaluation before each action. Non-cyclic drawdowns require a regular on-site evaluation and identification of need before each action. Drawdowns may be either partial or full. A partial drawdown is anything short of lowering the water level to the lowest elevation permitted by the structure. Similarly, a full drawdown lowers the water level to the lowest possible elevation. Both types of drawdown may vary in frequency, starting date, and duration. Drawdowns are made with reference to normal pool--the preferred height (elevation) of the water surface when the impoundment is considered full (fig. 1). Judicious prescriptions will permit the concentration of effort where it will be most beneficial and will include the objective and the criterion for judging success.

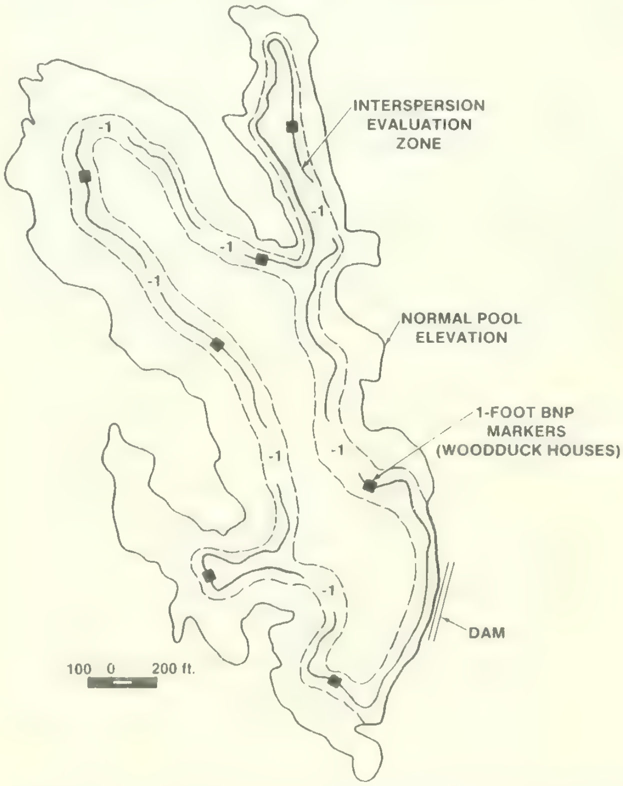

Figure 1.--*Impoundment overview illustrating the location of an interspersion evaluation zone centered on 1-foot BNP.*

The common goal in constructing and managing wildlife water-impoundments is to create and maintain deep marsh habitat primarily for producing waterfowl. Other wildlife are important, but priority is given to waterfowl. For effective waterfowl production the water level must be maintained at normal pool during nesting and brood rearing. During periods of drawdown an impoundment is obviously not ideal for production so there may be a tendency to minimize drawdown time without giving adequate consideration to whether or not drawdown objectives have been achieved. Under these circumstances drawdowns are viewed as "a means-to-an-end" with little value being placed on the drawndown habitat. Unfortunately, this view overlooks the importance of mud flats to a variety of shore birds and other animals that thrive in this environment. The point is, drawdowns should not be viewed as a necessary evil; they are valuable in and of themselves and there should be no reluctance to continue a drawdown through whatever time is required to achieve the desired change in the normal pool habitat. This may require more than 1 year of full drawdown to cause the desired change.

This chapter describes the response of wetland plant communities to water regimes that may or may not be subject to prescriptions. It is based primarily on the results of research conducted by the author in north-central Minnesota. However, visits to wetlands across the northern Lake States indicate that the principles discussed are generally applicable.

The following discussion is directed at understanding the physical and biological limitations that determine the outcome of a drawdown prescription rather than writing a universal prescription. With that understanding the biologist will be better prepared to write prescriptions that meet the somewhat unique properties of each impoundment.

A KEY TO OPPORTUNITIES FOR CONTROLLING WATER LEVEL

1. Mineral soil; or fibric (least decomposed) organic soils ≤ 6 inches thick; no extensive floating mats of organic soil and vegetation 3
   1. Organic soil, extensive, and > 6 inches thick; or extensive floating mats of organic soil and vegetation 2
2. Surface fibric (least decomposed) organic soil > 6 inches thick without an underling hemic (moderately decomposed) and/or sapric (most decomposed) layer that is > 1-foot thick; or extensive floating mats of organic soil and vegetation present .... Class A-1
   2. Hemic (moderately decomposed) of sapric (most decomposed) organic soil > 1-foot thick that may underlay fibric (least decomposed) surface layers (may be 6 feet or deeper) .... Class A-2
3. Soils not strongly calcareous in upper foot 5
   3. Soils strongly calcareous in upper foot .... 4[1]
4. Watershed area/impoundment area ≤ 0.75 × map value[2] .... Don't build
   4. Watershed area/impoundment area > 0.75 but ≤ 1.5 × map value .... Class B-1
   4. Watershed area/impoundment area > 1.5 but ≤ 3 × map value[2] .... Class B-2
   4. Watershed area/impoundment area ≤ 3 × map value[2] .... Class B-3
5. Watershed area/impoundment area ≤ 0.75 × map value[2] or specific conductance ≤ 25 micro mhos/cm .... Don't build
   5. Watershed area/impoundment area > 0.75 × map value[2] or specific conductance > 25 micro mhos/cm 6
6. Specific conductance ≤ 100 micro mhos/cm .... Class B-1
   6. Specific conductance > 100 micro mhos/cm 7
7. Watershed area/impoundment area ≤ 3 × map value[2] .... Class B-2
   7. Watershed area/impoundment area > 3 × map value .... Class B-3

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[1]*An estimate of impoundment management class before construction is tentative because the presence of calcareous material precludes the use of specific conductance for identification of water source and amount. Experience after construction may lead to a change in management class.*

[2]*See Verry 1983 (fig. 3)*

VEGETATION CLASSIFICATION

Plant species with the potential to occupy wetland sites throughout the Lake States are far too numerous for individual consideration in management schemes. In most cases we simply don't know enough about each species to successfully manage them intensively. The alternative is extensive management wherein they are classified according to similarity of growth form and habit. These groups are commonly referred to as life-forms as described by Golet and Larson (1974). The classification scheme used in this manuscript, and the assignment of species present in northern Minnesota, is summarized in the Appendix. The list is generally applicable across the forested region of the western Great Lakes.

Classification of whole wetlands typically depends on the composition and distribution of vegetation. The most widely known wetland classification system with wildlife management emphasis was developed by Shaw and Fredine (1956). A brief summary of their pertinent Wetland Types is presented in table 1, (Verry 1983) with a cross reference to a latter system developed by Cowardin *et al.* (1979). The Shaw and Fredine system will be used in the following discussion.

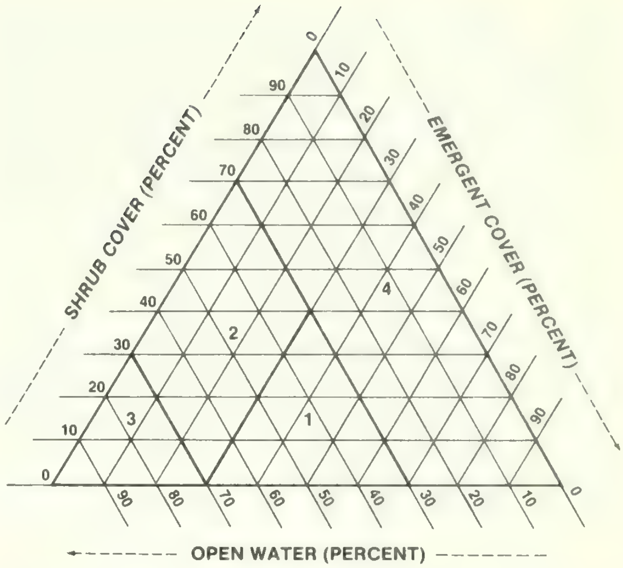

Figure 2.--*Potential interspersion of shrubs, emergents, and open water based on percent cover at the 1-foot below normal pool elevation. Four interspersion conditions are recognized.*
1. Good interspersion of vegetation and water,
2. Fair interspersion with shrubs dominate,
3. Poor interspersion--too much open water, and
4. Poor interspersion--too little open water.

WHEN SHOULD AN IMPOUNDMENT BE DRAWN DOWN?

Management objectives will determine the appropriate drawdown prescription for impoundments. Typical objectives are:

1. Improve or maintain waterfowl nesting and brood habitat,
2. Improve or maintain availability of food plants for transient waterfowl,
3. Improve, maintain, or reduce fish or fur-bearer habitat, or
4. simply maximize productivity and diversity of a management area.

The biologist must determine what prescription will be used to achieve specified objectives. There is no one prescription that can be applied universally but there are general principles associated with drawdowns that must be considered in preparing prescriptions. These principles are discussed in section V as they relate to various impoundment management classes.

Let's assume that the first objective listed above is to guide the preparation of a drawdown prescription for a management area consisting of several impoundments. The habitat of each impoundment should first be examined. In a simplistic examination, the potential spectrum of principle wetland habitat components (shrubs, emergents, open water) can be integrated as seen in figure 2. Each is expressed as a percent of total cover in a triangular grid. Percent cover must be estimated visually during a visit to each impoundment. The zone centered at 1 foot below normal pool elevation (1-foot BNP) is the key zone for this estimate. Make the estimate with the water level at normal pool, and no earlier than July 15 each year. An aerial survey with a small aircraft is probably the least expensive method. Permanent markers should be established in each wetland for identification of the 1-foot BNP zone. A series of wood duck houses at this elevation would make ideal markers.

Each impoundment may be located within the grid to illustrate its position with respect to four conditions of vegetation interspersion. These are:

Condition 1--good interspersion of vegetation and open water,
Condition 2--fair interspersion but shrubs dominate at the expense of emergents,
Condition 3--poor interspersion--too much open water, and
Condition 4--poor interspersion--not enough open water.

When waterfowl are the focus, the impoundment should be maintained in Condition 1. If an impoundment is judged to be in either of the other conditions,

then a drawdown should be prescribed to alter the habitat accordingly. Plotting the progress of an impoundment through several years will provide a valuable record of the prescription success and will guide the process of updating the prescription. Prescriptions must be dynamic to accommodate the unexpected events that inevitably occur and that alter the condition of an impoundment.

Although the habitat condition grid in figure 2 may be used for guiding the management of specific impoundments, its greatest utility may be in the simultaneous evaluation of any number of impoundments within a management area. By plotting several impoundments on the same grid, the manager can quickly evaluate the overall habitat condition. The least desirable would be to have the majority of the impoundments clustered within either Condition 2, 3, or 4. This may indicate a general problem in achieving management goals. If the majority are close to or within Condition 1 then the idealized goal is being achieved and prescriptions are on track.

WATER-IMPOUNDMENT MANAGEMENT TYPES AND OPTIONS

The KEY TO OPPORTUNITIES FOR CONTROLLING WATER LEVEL may be used to direct the user to particular impoundment management classes described in this section, or the section may be read in its entirety for an overview of the management options available for impoundments in the western Great Lakes. The management strategy favored by the author would have several impoundments within an administrative land unit, be it a national forest, state forest, refuge, etc., with the goal being to maximize wildlife habitat diversity throughout the unit. The manager needs to identify deficient wetland habitat types; or identify opportunities to convert to more productive sites when a specific form of wildlife is to be favored (Verry 1983).

Class A-1.--Extensive Floating Mats

When a surface organic soil horizon exceeds 6 inches in thickness and is vegetated by non-woody plants (ericacous shrubs may be an exception), raising the water level by impounding water will very likely result in a floating mat. Existing plant roots bind the mat together but apparently do not anchor it to mineral soil. Apparently, a cleavage develops between the root mass and underlying less consolidated organic material or the mineral layer, permitting the mat to float up with the rising water level. Under pre-impoundment conditions these sites are typically wet as evidenced by the presence of the original organic soil. Therefore, the mat will persist during subsequent drawdown with little or no change and will simply float again when the water level returns to normal pool. Obviously, water-level manipulation is an ineffective management technique for floating mats and these wetlands will persist as Type 2 inland fresh meadows. Mats cause an additional problem if sections break away from the main mat and plug the spillway. This may result in excessive high water and unwanted flooding which may also pose a risk to the structure.

Impoundments with floating mats are not necessarily undesirable; in fact, during the early years after impoundment they may be exceptionally productive. The key will be good interspersion of open water (not less than 30 percent of an area) and floating mat as described in the previous section. When a potential exists for extensive continuous mats to begin floating immediately after construction, the impoundment should be considered a questionable venture because its effective life may be very short. On the other hand, impoundments with only localized development of sedge mats may be desirable because of the diversity that they can add within a wetland.

Organic soils with trees and tall shrubs do not usually float when newly flooded. These communities change dramatically during initial flooding because the woody plants are killed. All trees native to the Lake States are adversely affected. Speckled alder, a large common shrub, is also sensitive to flooding and will be killed. Willows, although somewhat more tolerant of flooding is continuous through the growing season (Knighton 1981). Organic soils supporting ericaceous shrubs may float with little diverse effect on the shrubs.

Willow survival can be encouraged by regular partial drawdowns that provide a minimum of 6 inches of drained soil[3]. Drawdowns should be made no later than July 15 to ensure healthy shrub growth. Speckled alder also can benefit from partial drawdowns if the drawdown occurs before June 15, but this seriously limits the time at normal pool, a critical factor in waterfowl brood management.

Class A-2--Protection Against Erosion of Deep Peats

Flooded peats (over 6 inches thick) around the edges of large multi-purpose impoundments (1,000-acres-plus size) can be subject to severe erosion[4]. The problem arises on areas receiving large spring runoff (> 1,000 cubic feet per second) if the impoundment is held

[3]*Data on file at the Forestry Science Laboratory, North Central Forest Experiment Station, Grand Rapids, MN.*

[4]*Personal communication from Arlyn Linde, Wisconsin DNR, Oshkosh, WI.*

at normal pool over winter, Then, if ice freezes deep enough to grab plant roots and the organic soil, spring flows will lift 6 inches or so of soil with the ice, pulverize it with wind-pushed ice, and flush it out in overflow. This annually deepens the shallow wildlife zone around an impoundment edge. In this situation erosion can be prevented by drawing water down during the winter. Begin drawdowns after 3 inches of ice has formed and achieve a water-level drop of 2 to 3 feet. This provides for spring flood retention, but it also leaves a collapsed layer of 3 inches of ice on the top of the shallow areas with organic soil. These "mud flats" will melt out in the spring prior to the snowmelt peak flow. Starting drawdown with 3 inches of ice protects muskrat populations, otherwise drawdowns can start after the waterfowl season ends.

Continue with step 3 in the key to determine the dependability of water supply.

B-1. Inadequate Water Supply

An inadequate water supply limits the management potential of these wetlands but does not exclude them from being desirable components of the habitat. However, they will revert to inland fresh meadows (Type 2) or inland shallow marshes (Type 3) during the growing season in normal and dryer than normal years despite drawdown prescriptions. In wetter than normal years they will remain flooded, approximating an inland deep marsh (Type 4). Water level management efforts will be most effective if directed at maintaining water levels as near to normal pool as possible. Normal weather fluctuations will provide sufficiently frequent natural full and partial drawdowns to usually eliminate the need for planned drawdowns. A prescription of cyclic drawdowns (every 5 years) will simply leave these impoundments dry or in low water for too long. In the event of several consecutive wet years a planned drawdown might be desirable if a need to adjust the habitat has been identified. The manager must realize that refilling an impoundment in Class B-1 is dependent on precipitation and not just the replacement of stop logs in the outflow structure. The response of wetland vegetation to drawdown in three impoundments on the Chippewa National Forest that had inadequate water supplies were studied for 4 years (Knighton 1982). Weather-caused drawdowns of varying duration and frequency were observed. The following discussion of what can be expected in similar impoundments is based on those studies.

Meadow emergents (See Appendix, table 3) will be the prevailing plants at elevations near normal pool. Their expected distribution is illustrated in figure 3 for high and low water years. Their peak biomass will occur at about 1 foot below normal pool but will shift downward an additional foot and increase during low water years. These emergents are perennials, [primarily sedges (*Carex* spp. L)] and a variety of grasses that persist to some extent even during extended flooding. When the water level is dropped, meadow emergents will expand vegetatively and quickly occupy the site. Two years of exposed soils or at least intermittently exposed soils will be needed for invasion from seed assuming that a viable seed supply exists.

Mudflat emergents (See Appendix, table 3) are also a very important component of the vegetation in these impoundments. Their biomass will show extreme fluctuations from high to low water years and they will be particularly prevalent during drawdown at 2- and 3-feet BNP where competition with meadow emergents is lessened by previous flooding (fig. 3). Mudflat

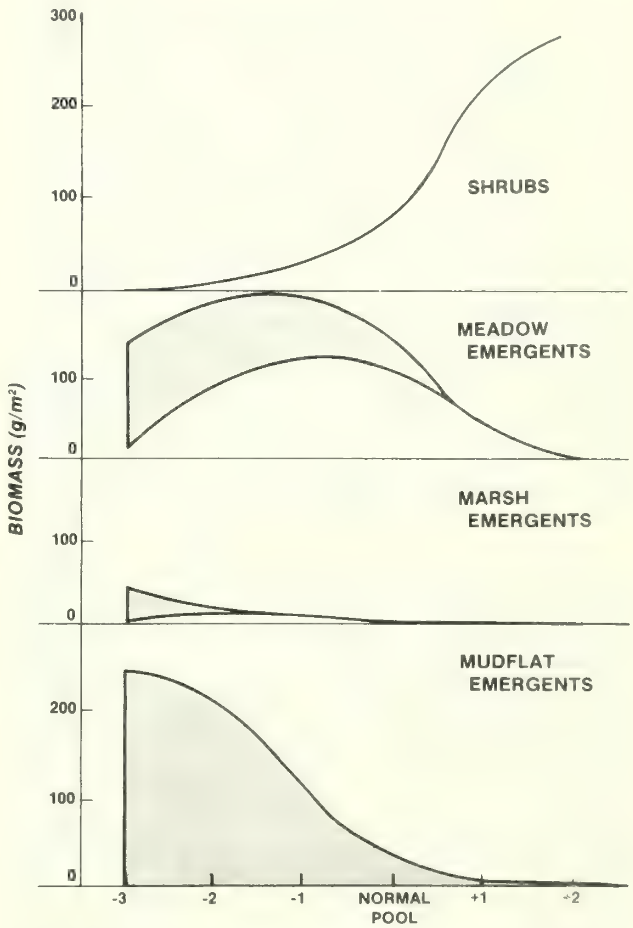

Figure 3.--*Effects of drawdown and normal pool water levels on shrub and emergent biomass distribution in impoundments having an inadequate water supply for precise water-level management (Class B-1 impoundments). For emergents the upper line approximates biomass distribution during full drawdown and the lower line approximates biomass when the water level is near normal pool throughout the year.*

emergents are typically annuals or biennials that require moist, unvegetated soils for successful germination and growth to maturity. To a very limited extent, the biennials are able to persist into their second year even if water levels increase. They are prolific seed bearers, but the seeds apparently lose their viability if flooded continuously for several years. Several are successful late season germinators, particularly the biennials, and will establish even if water levels remain high until late summer. Maturity is most successful if in the following year water levels remain low.

Typically, mudflat emergents are sensitive to flooding and disappear quickly when water levels rise. They must be considered transient but their seeds provide valuable wildlife food and when dead they offer an ideal environment for many invertebrates that feed on micro-organisms that are active on decaying tissue.

Marsh emergents have difficulty surviving through several years given fluctuating wet-dry conditions that prevail in impoundments with inadequate water. They are typically perennials (Appendix, table 3), and require more stable water regimes. During the wettest years they will be most abundant at an elevation about 1 foot BNP (fig. 3), but will represent only 2 percent of the total herbaceous biomass. During years of low water they will appear at lower elevations in a manner paralleling that of invading mudflat emergents but will represent only 10 percent of the combined biomass. Subsequent reflooding will quickly eliminate any gains that accrue during low water. Even short term flooding of two to three feet will severely limit their distribution. As long as the ideal water depth for marsh emergents is continually shifting within an impoundment their success will be limited.

Floating-leaved and submergent vegetation (Appendix, table 4) will be limited to areas where pools persist. Submergents may be dense (> 300 g/m^2) in residual pools during low water at elevations 3 or mmore feet BNP. And they can invade at higher elevations as the water level moves up during wet periods. Widely scattered individuals will invade and the biomass will be low, < 60 g/m^2 at one foot BNP. Floating-leaved vegetation will be essentially non-existent regardless of elevation and there will be little opportunity to increase this life-form in the absence of more stable water-levels.

In the event that a series of consecutive wet years occurs, submergents may become locally dense. A drawdown will dramatically reduce the biomass the first year of reflooding but subsequent reinvasion should be expected if consecutive wet years occur.

These impoundments will have a shrub perimeter that is most developed at 2-feet above normal pool elevation. At and below normal pool shrubs will be essentially absent. Willows and alder will prevail. Willows tend to be a little more resistant to continuous flooding through the growing season than alders and even resprout vigorously after a period of high water that has left the aerial parts obviously dead. As indicated earlier, the typical water regime in impoundments with an unmanageable water supply favors meadow emergent vegetation at elevations below normal pool. These emergents are very effective at competing with shrubs and contribute to their exclusion (fig. 3). Emergent recovery after flooding is much quicker than shrubs, contributing to their competitive edge.

B-2.--Adequate Water Supply; Prescriptions are Least Difficult to Apply

These impoundments have adequate water for water-level management and are likely to be most successful. The reason is simple--the water supply is moderate and therefore more easily maintained near the desired level. The key is replacement-time, or the time required on the average for a complete exchange of water during the growing season. For these impoundments the replacement-time is measured in weeks; for example, if beaver are actively damming the outlet, a visit to remove the dam every week is adequate. Impoundments with replacement-times measured in days require almost daily visits to prevent flooding when beaver are active (in the forested region of the Lake States it's always safe to assume that beaver will be active in all impoundments). Given an adequate water supply beaver are the single most important factor in the failure to meet a water-level prescription. Methods of minimizing beaver problems are discussed by Buech (1983).

Even with precise control, water-level manipulation is frequently over-rated as an effective wetland habitat management tool. Other factors (Phillips 1970) such as the degree of substrate drainage during drawdown, the amount of surface soil relief throughout the wetland, and substrate composition are more important in determining interspersion of vegetation than is water-level manipulation, *per se.* Soil relief, or the degree of irregularity in the soil surface will strongly influence the degree of interspersion of vegetation and open water that will exist. Basins with a uniform soil surface will develop monotonous vegetation despite planned drawdowns because the soil water regime will be essentially the same over extensive contiguous areas. Typically, plants will segregate into concentric zones limiting interspersion to one dimension. Drawdowns will shift the zones up and down the slope but any mixing of zones is very short lived. If the zones are interrupted by localized irregularities in the soil

surface, then lasting interspersion of vegetation on a second dimension will exist.

Monotonous basins are particularly prevalent in the western Great Lakes region because the climate favors peat formations. Localized irregularities in the mineral soil surface within basins have largely been flattened out by peat accumulation. Interspersion can be substantially enhanced by extensive scraping and piling of soil to form small islands along the original 1-foot-below-normal-pool contour. Although water-level manipulation may be simpler to implement then forming islands, it is by no means as effective.

The response of wetland vegetation to drawdown in two impoundments of Class B-2 on the Chippewa National Forest was studied for 4 years (Knighton 1982). The drawdowns were started in late summer and lasted through the next growing season. The impoundments were about 3 and 4 years old when the study began and the drawdowns were applied during the study at 5 years of age. The prescription was the same uniform 5-year drawdown cycle that has been applied to all impoundments on the Chippewa until recently. It includes an annual partial drawdown about 1 foot, beginning in late summer. The purpose of the partial drawdown has been to encourage shrub growth at elevations below normal pool. The results lead to the following generalizations about 5-year cycles.

Drawdowns will sharply increase emergent plant biomass at depths from normal pool down to 3-feet BNP. The sharpest increase will be at 3 feet where emergents are essentially non-existent prior to drawdown (fig. 4). The increase in emergents will be shortlived, disappearing during the first year after drawdown. The long term response of emergent plant biomass to this drawdown prescription (for the elevation 1-foot BNP) is characterized by sharp peaks and low stable valleys but essentially no lasting change in vegetation biomass persists between drawdowns (fig. 5). The effects of this drawdown prescription on plant species composition follows an identical pattern to that of biomass. There is simply very little lasting change, if any. The prevailing view--that changes in vegetation brought about by drawdown only slowly disappeared over several years--simply does not materialize here. The result is that there are three habitat conditions associated with a cyclic drawdown prescription. They are:

1. Large quantities of emergent biomass and some change in emergent composition during drawdown,
2. Large quantities of dead emergent biomass submerged and decaying during the first year after drawdown, and
3. Small quantities of living and dead emergent biomass during all other years.

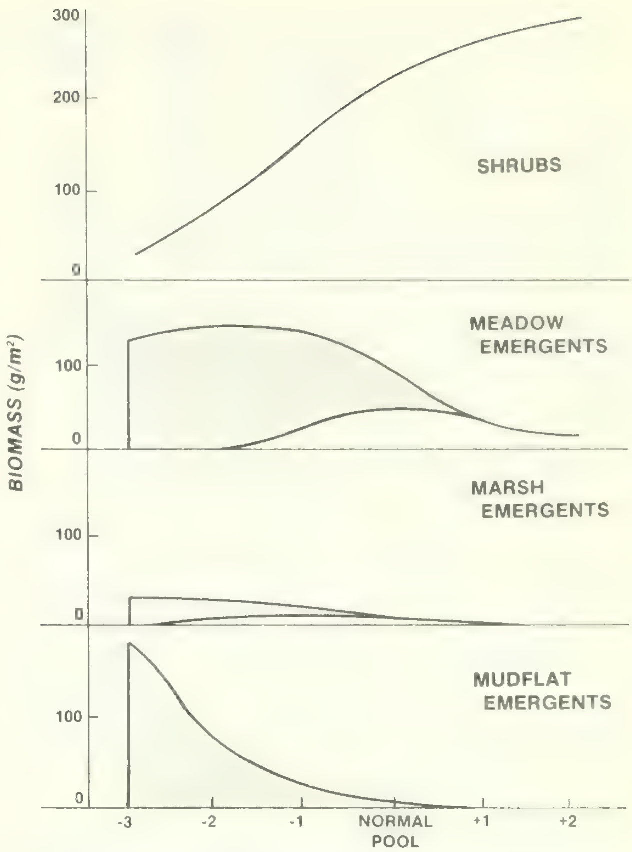

Figure 4.--*Effects of drawdown and normal pool water levels on shrub and emergent biomass distribution in impoundments where water-level management is least difficult (Class B-2 impoundments). For emergents the upper line approximates biomass distribution during full drawdown and the lower line approximates biomass when the water level is near normal pool throughout the year.*

In general, the response of particular plant lifeforms to drawdown will follow the same patterns described for impoundments that were unmanageable because of an inadequate water supply (B-1). There will be some differences that warrant consideration and they will be discussed with reference to the above mentioned section.

Meadow emergents (See Appendix, table 3) will be the prevailing emergent plant but the biomass will be only 20 percent of that found at 1-foot BNP in B-1 impoundments during normal pool years. The difference will be even greater at lower elevations (fig. 4). The low plant productivity is due to more stable water levels during the growing season and this despite partial annual drawdowns that may be applied the last half of each summer. During drawdown the biomass increase will actually be greater but the total will still be about 70 percent of that in B-1 impoundments at

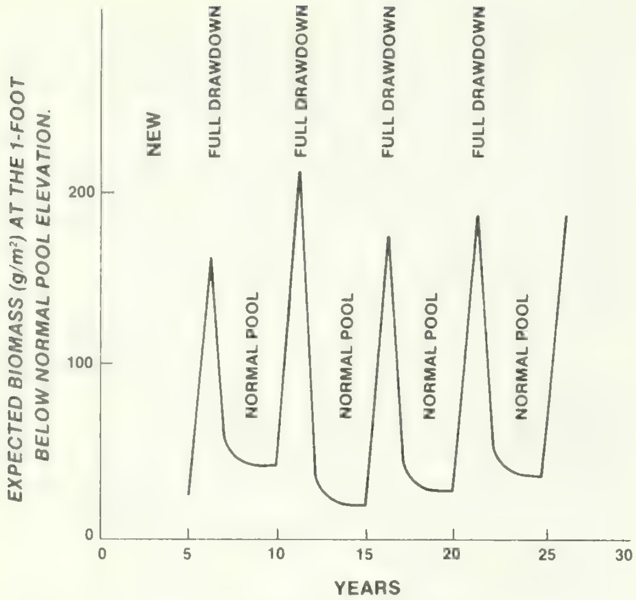

Figure 5.--*Expected response of emergent plant biomass to a full drawdown at 5 year intervals in impoundments that are least difficult to manage (Class B-2). The curves are generalized and extrapolated from 4 years of study on two impoundments.*

1-foot BNP. During normal pool years meadow emergents will be insignificant at elevations lower than 1-foot BNP.

Marsh emergents (See Appendix, table 3) will have a very limited distribution in B-2 impoundments. They will increase somewhat during drawdown but disappear with reflooding (fig. 4). They will be excluded from their most favorable water depth (normal pool down to 1-foot BNP) by partial annual drawdowns. They simply can't survive the late summer drawdown above 1-foot BNP and they are eliminated by early season deep flooding at lower elevations. They will be favored only by full-year stable water levels for several consecutive years.

Mudflat emergents (see Appendix, table 3) will be absent during normal pool years and increase somewhat during drawdown (fig. 4). At 1-foot BNP they will invade with only 20 percent of the invasion biomass of B-1 impoundments. At 3-feet BNP they will invade at 70 percent of B-1 biomass. Why mudflat emergents are less successful invaders in B-2 impoundments isn't clear but there is reason to expect that fewer viable seeds are present, particularly at lower elevations where flooding is more persistent. Also, drawdowns are less frequent, or occur later in the season in the case of partial drawdowns, and seed production is therefore less dependable.

Floating-leaved (Appendix, table 4) plant biomass will occur as a trace < 1 percent) at 3-feet BNP during normal pool years. These plants are typically slow to establish themselves and are very sensitive to drawdown or competition with emergents. They will have very limited success in impoundments receiving full drawdowns at 5-year intervals or less.

Submergents (Appendix, table 4) will dominate (90 percent) the herbaceous biomass at 3-feet BNP and lower elevations during normal pool years. Their importance will decrease rapidly as water level increases and will represent only 4 percent of the herbaceous biomass at 1-foot BNP.

Shrub biomass (predominately willows) will occur at all elevations below normal pool (fig. 4). The biomass at 1-foot BNP will be about 150 g/m^2 or 50-60 percent of the shrub biomass at 2-feet *above* normal pool. From there it will drop off to 25 g/m at 3-feet BNP. This is substantially more shrub biomass than will be found in B-1 impoundments where water levels decline progressively through the summer and is attributed to effects of partial annual drawdowns combined with the reduced competition with meadow emergents that occurs when the water level is held at normal pool during the first half of the growing season. Partial drawdowns should begin no later than July 15 to assure that willows will remain healthy. If alders are wanted, partial drawdowns must begin no later than June 15 at the latest.

As previously stated, the number of years between full drawdowns has little lasting effect on impoundment vegetation. On the other hand, drawdowns lasting more than 1 year will increase the biomass of meadow emergent vegetation present at the end of a drawdown. In impoundments where meadow emergent biomass is insufficient at 1-foot BNP, 2 consecutive years of drawdown will be needed for it to increase substantially.

B-3 Adequate Water Supply; Prescriptions are Most Difficult to Apply

The response of these impoundments to various water level regimes is very similar to that discussed for management type B-2 impoundments. The difference is in the amount of time and energy that must be expended by field personnel to assure that water levels meet the prescription. These impoundments have water replacement times measured in days and therefore require almost daily visits to assure success. If the impoundments are not checked frequently for beaver damming, the animals will probably control the water level despite special structures intended to thwart their dam building efforts. Buech (1983) suggests some structures that may prove more effective.

CATTAIL IN WATER IMPOUNDMENTS

Cattail, a robust emergent, frequently will encroach on other wetland vegetation and become dominant. Found everywhere, it annually produces large quantities of biomass in monotypic communities. Because of its prevalence it is probably our most thoroughly studied wetland plant genus and specific practices have been proposed for its management and control (Beule 1979). Desirability of a cattail community will depend on its stem density and interspersion with other vegetation and open water, and the wildlife that are to be favored.

Broad-leaf cattail was either already established in all of my study impoundments at the beginning, or it became established during the 4 year course of the study. In any event, its distribution within impoundments definitely increased, apparently irrespective of management on the impoundment. Conditions that most favor encroachment and the effects of drawdown were observed.

Cattail invasion by seed will occur on mineral soil that remains poorly drained during drawdown and that already has very little sedge or grass to compete. Once established, cattail will endure several years of continuous flooding while expanding vegetatively. Drawdowns will only reduce cattail populations if the soil is permitted to drain thoroughly within the rooting zone. Persistent rainfall, heavy textured soils, or both will reduce the effectiveness of drawdowns. Two or more years may be needed for a suitable kill.

The presence of an organic soil suggests inherent poor drainage so that opportunities for cattail management by drawdown are very limited. Cattail will become established on an exposed organic soil as readily as on mineral soil when it does not have to compete with established sedge or grass. Typically, sites having an organic soil will not drain adequately to dry out the soil unless major changes are made in local drainage patterns. During drawdown cattail will flourish on wet soils rather than die out, and at normal pool it will do well when flooding depth is less than 2 feet. Other methods of control must therefore be used.

Floating cattail mats have been observed to rise 4 to 5 feet in the deeper areas of impoundments and then to subside with the water level during breakdown. The shoreweed edges of the floating mats can be repeatedly trimmed to the area of the persistently saturated substrate by using full drawdowns lasting at least through one growing season. Drawdowns therefore may be used to limit the expansion of floating cattail mats to some extent but they will not eliminate them or significantly alter stem density throughout the poorly drained areas of an impoundment.

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APPENDIX

Table 1.--*Species assignment to the tree life-forms*

Life-form and scientific name	Common name
TREES	
Live deciduous	
Acer saccharum Marsh.	Sugar maple
A. spicatum Lam.	Mountain maple
A. rubrum L.	Red maple
Betula papyrifera Marsh.	White birch
Fraxinus nigra Marsh.	Black ash
Populus grandidentata Michx.	Bigtooth aspen
P. balsamifera L.	Balsam poplar
P. tremuloides Michx.	Quaking aspen
Prunus pensylvanica L.f.	Pin cherry
P. virginiana L.	Choke cherry
P. serotina Ehrh.	Black cherry
Quercus alba L.	White oak
Q. borealis Michx. f.	Red oak
Q. macrocarpa Michx.	Burr oak
Q. ellipsoidalis E.J. Hill.	Scarlet oak
Tilia americana L.	Basswood
Ulmus americana L.	American elm
U. rubra Muhl.	Slippery elm
Live evergreen	
Abies balsamea (L.) Mill.	Balsam fir
Picea glauca (Moench) Voss.	White spruce
P. mariana (Mill.) BSP	Black spruce
Pinus strobus L.	White pine
P. banksiana Lamb.	Jack pine
P. resinosa Ait.	Red pine
Thuja occidentalis L.	N. white cedar

Table 2.--*Species assignment to the shrub life-forms*

Life-form and scientific name	Common name
SHRUBS	
Tall slender	
Alnus rugosa (DuRoi) Spreng.	Speckled alder
Amelanchier spp. Medic.	Service berry
Ostrya virginiana (Mill.) K. Koch	Ironwood
Bushy	
Cornus stolonifera Michx.	Red-osier dogwood
Diervilla lonicera Mill.	Bush honeysuckle
Lonicera spp. L.	Honey-suckle
Salix spp. L.	Willow
Viburnum Rafinesquianum Schult.	Downy arrowwood
V. opulus L.	High-bush cranberry
V. lentago L.	Sheepberry
Low compact	
Arctostaphylos uva-ursi (L.) Spreng.	Bearberry
Chamaedaphne calyculata (L.) Moench.	Leather-leaf
Gaultheria procumbens L.	Wintergreen
Ledum groenlandicum Oeder.	Labrador tea
Vaccinium myrtilloides Michx.	Blueberry
V. angustifolium Ait.	Blueberry
Low sparse	
Corylus americana Walt.	Hazel
C. cornuta Marsh.	Beaked hazel
Rhamnus alnifolius L'Her.	Buckthorn
Ribes spp. L.	Gooseberry
Rosa spp. L.	Wild rose
Rubus spp. L.	Blackberry
Spiraea spp. L.	Spirea

Table 3.--*Species assignment to the emergent life-forms*

Life-form and scientific name	Common name
EMERGENTS	
Mudflat	
Alisma plantago-aquatica L.	Water plantain
Alopercurus aequalis Sobol.	Foxtail
Bidens spp. L.	Begger-ticks
Chenopodium album L.	Lamb's quarters
Cicuta maculata L.	Water hemlock
C. bulbifera L.	Water hemlock
Epilobium adenocaulon Haussk.	Willow-herb
Erechtites hieracifolia (L.) Raf.	Fireweed
Eupatorium maculatum L.	Joe-Pye weed
E. perfoliatum L.	Boneset
Galium spp. L.	Bedstraw
Geum spp. L.	Avens
Impatiens biflora Willd.	Jewelweed
Laportea canadensis (L.) Gaud.	Wood nettle
Lycopus uniflorus Michx.	Bugle-weed
L. americanus Muhl.	Bugle-weed
Melampyrum lineare Desr.	Cowwheat
Mentha arvensis L.	Mint
Mimulus ringens L.	Monkey-flower
Naumburgia thyrisiflora (L.) Duby.	Tufted loosestrife
Polygonum cilinode Michx.	Bindweed
P. lapathifolium L.	Smartweed
P. sagittatum L.	Smartweed
P. punctatum Ell.	Smartweed
Potentilla spp. L.	Cinquefoil
Rorippa islandica (Oeder) Borbas.	Yellow cress
Rumex spp. L.	Dock
Scutellaria galericulata L.	Skullcap
S. lateriflora L.	Skullcap
Solidago spp. L.	Goldenrod
Stachys palustris L.	Hedge hettle
Triadenum virginicum (L.) Raf.	Marsh St. John's-wort
Urtica dioica L.	Nettle
Robust	
Phragmites communis Trin.	Reed
Typha latifolia L.	Broad-leaf cattail

(Table 3--continued)

(Table 3--continued)

Life-form and scientific name	Common name
Tall meadow	
Acorus calamus L.	Sweet flag
Iris versicolor L.	Blue flag
Phalaris arundinacea L.	Reed Canary grass
Zizania aquatica L.	Wild rice
Short meadow	
Carex spp. L.	Sedge
Dulichium arundinaceum (L.) Britt.	Three-way sedge
Gramineae	Grass
Argrostis spp. L.	Bent Grass
Calamagrostis spp. Adans.	Bluejoint
Leersia oryzoides (L.) Sw.	Cut-grass
Oryzopsis spp. Michx.	Rice grass
Poa spp. L.	Wild rice
Juncus spp. L.	Rush
Narrow-leaved marsh	
Eleocharis spp. R. Br.	Spike rush
Equisetum sylvaticum L.	Horsetail
E. palustre L.	Horsetail
E. fluviatile L.	Horsetail
Scirpus validus Vahl.	Great bulrush
S. subterminalis Torr.	Bulrush
S. americanus Pers.	Bulrush
Scirpus spp. L.	Bulrush
S. cyperinus (L.) Kunth.	Wool grass
Sparganium fluctuans (Morong.) Robins.	Bur-reed
S. chlorocarpum Rydb.	Bur-reed
Sphagnum spp. Dill	Sphagnum
Broad-leaved marsh	
Calla palustris L.	Water arum
Campanula aparinoides Pursh.	Bellflower
Polygonum natans Eat.	Water smartweed
Potentilla palustris (L.) Scop.	Marsh cinquefoil
Ranunculus pensylvanicus L.f.	Buttercup
R. Gmelini DC.	Yellowwater-crowfoot
Sagittaria latifolia Willd.	Arrow-head
Sium suave Walt.	Water parsnip

Table 4.--*Species assignment to floating-leaved and submergent life-forms*

Life-form and scientific name	Common name
Floating-leaf	
Brasenia Schreberi Gmel.	Water-shield
Nuphar variegatum Engelm.	Spatterdock
Nymphaea tuberosa Paine.	Water lily
Submergents	
Ceratophyllum demersum L.	Coontail
(Moss)	Moss
Myriophyllum spp. L.	Water milfoil
Potamogeton natans L.	Floating-leaf pondweed
Potamogeton spp. L.	Pondweed
Utricularia vulgaris L.	Bladderwort

Table 5.--*Species assignment to upland herbaceous life-form*

Life-form and scientific name	Common name
Upland herbaceous	
Achillea millefolium L.	Sheep yarrow
Amphicarpa bracteata (L.) Fern.	Hog peanut
Anaphalis margaritacea (L.) Benth. & Hook.	Pearly everlasting
Anemone quinquefolia L.	Anemone
Apocyrum androsaemifolium L.	Dogbone
Aralia nuducaulis L.	Wild sarsaparilla
Asarum canadense L.	Wild ginger
Aster macrophyllus L.	Wild aster
A. cordifolius L.	Wild aster
Athyrium Filix-femina (L.) Roth.	Lady-fern
Botrychium spp. Sw.	Adder's-tongue
Circea alpina L.	Enchanter's nightshade
Cirsium arvense (L.) Scop.	Canada thistle
Clintonia borealis (Ait.) Raf.	Clintonia
Coptis trifolia (L.) Salisb.	Goldthread
Cornus canadensis L.	Bunchberry
Dryopteris spp. Adans.	Shield-fern
Fragaria spp. L.	Strawberry
Galium triflorum Michx.	Bedstraw

(Table 5 continued)

(Table 5 continued)

Life-form and scientific name	Common name
Geranium robertianum L.	Herb robert
Hepatica americana (DC.) Ker.	Hepatica
Heracleum lanatum Michs.	Cow parship.
Lactuca canadensis L.	Lettace
Lathyrus spp. L.	Vetchling
Lycopodium obscurum L.	Ground pine
Maianthemum canadense Desf.	Maian-themum
Mitella nuda L.	Bishop's cap
Osmorhiza claytoni (Michx.) Clarke.	Sweet cicely
Osmunda claytoniana L.	Interrupted fern
Parthenocissus quinquefolia (L.) Planch.	Virginia creeper
Petasites sagittatus (Pursh) Gray.	Sweet coltsfoot
Polygonatum biflorum (Walt.) Ell.	Solomon's seal
Potentilla norvegica L.	Cinquefoil
Prunella vulgaris L.	Self-heal
Pteridium aquilinum (L.) Kuhn.	Bracken fern
Pyrola spp. L.	Shinleaf
Sanguinaria canadensis L.	Bloodroot
Senecio spp. L.	Groundsel
Smilacina trifolia (L.) Desf.	False solomon's seal
Streptopus spp. Michx.	Twisted-stalk
Taraxacum officinale Weber.	Dandelion
Thalictrum dioicum L.	Meadow rue
Trientalis borealis Raf.	Star-flower
Trifolium pratense L.	Red clover
Trillium spp. L.	Trillium
Uvularia grandiflora Sm.	Bellwort
U. perfoliata L.	Bellwort
Vicia spp. L.	Vetch
Viola spp. L.	Violet
Waldsteinia fragaroides (Michx.) Tratt.	Barren strawberry

VEGETATION MANAGEMENT IN WATER IMPOUNDMENTS: ALTERNATIVES AND SUPPLEMENTS TO WATER-LEVEL CONTROL

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CONTROL BURNING

Controlled burning to change and improve wetland habitat has been used by game managers throughout Wisconsin for many years. It is one of the cheapest tools available for large scale habitat changes. These changes can be either short or long term, depending on the nature of the fire.

However, burning is not without restrictions. Burns that get out of control can be very damaging and dangerous. Poorly scheduled spring burns are a menace to nesting wildlife. Burns made without consideration for the proximity of highways and inhabited areas can cause irritating smoke problems, and poor visibility may result in dangerous highway conditions.

A plan of operation that considers all aspects of the burn and provides for back-up systems to cover foreseeable emergencies should be made in advance. It is necessary to be aware of the problems and try to resolve them. Most important, burns should not be made without an experienced crew with enough personnel to safely do the job. Clearance for the burning should be obtained in advance from the local fire protection district.

REASONS FOR BURNING

Removal of the Annual "Rough"

Removing the dead canopy of the previous summer's vegetation biomass is one of the objectives of most of the game managers who burn wetlands in Wisconsin. However, in some areas it is stressed more than in others. Some of the large marshes in the southern half of the State have extensive portions of the dense peripheral marsh cover burned off whenever conditions for burning are suitable in the early winter or early spring. A good solid ice cover and a minimum of snow are a necessity to make the burn area accessible and to assure that most of the vegetation will be removed by the fire. Since the entire marsh is never burned in any operation, cover for wildlife always remains. Without periodic controlled burns, the shallow peripheral areas of the marsh become dense tangles of dead and living vegetation which makes travel difficult and restricts wildlife use. A winter burn on these areas creates openings that often receive a considerable amount of waterfowl use in the spring. Burned areas green up first, producing succulent new shoots often heavily favored by geese. On burned areas, many seeds produced during the previous growing season are exposed for waterfowl use. Since large quantities of vegetation are removed by the fire, the natural build-up of the marsh floor is slowed and plant succession is held back.

Reduction of Marsh Floor Levels by Fire

This is done only with a very hot, slow-moving fire under dry surface conditions. Extreme heat from the fire ignites the organic soils and causes them to burn downward into the underlying peat. This results in the burning out of depressions that can improve a dense uninterrupted marsh cover. When water conditions return to normal, these bare holes will fill with water and produce some natural appearing potholes. However, there are problems associated with peat burns that should be carefully considered. Burning peat is extremely difficult to extinguish. It slowly burns deeper and deeper into the ground and unless the area can be reflooded, the fire may continue to burn for days, or even months. Peat fires that occurred during the drought years in the 1930's burned many holes in the floors of our dried out marshes. Some of these fires actually continued to burn for years as the drought continued. Smoke clouds from these fires covered large areas and were a source of more than a little annoyance. Considering the problems we already have with air pollution, long-burning peat fires would hardly be considered acceptable, even if they do improve the wetland habitat. Peat burns, whether intentional or unintentional, seem to be quite attractive to waterfowl.

But burns should only be encouraged if they can be controlled and extinguished within a reasonable period of time.

Control of Woody Vegetation

This is one of the most common objectives for burning in Wisconsin. Without controlled burning, shrubs tend to gradually invade the peripheral sedge-grass meadows and produce a shrub swamp. Fire is the most economical means of retarding this encroachment. To produce an effective burn there must be sufficient understory of grass and herbaceous material to provide fuel for a hot burn and good top kill. Burning should take place in August and September when the woody species are still actively growing. Any vegetation is more susceptible to injury during its period of active growth. In some areas the objective has been to remove woody cover from the lowland meadows and restore the original prairie cover. Summer or hot weather burning is certainly more effective in controlling woody cover than dormant season burning. Late summer or early fall burning, after the active nesting season is past, will cause much less damage to wildlife.

Destruction of Sphagnum to Bring About a Recession to Grasses

Many of the waterfowl impoundments in northern Wisconsin contain areas of sphagnum and leatherleaf bog. Hot fires during the summer and early fall are very effectively used to set these species back and produce conditions suitable for a change to grasses and sedges which are more useful for waterfowl and sharptail grouse management.

Cleaning Impoundment Basins Prior to Flooding

Before flooding an area that contains a large amount of ground litter and woody cover, it is desirable to remove as much of this material as possible through a preflooding burn. A burn will hasten the death of the shrub cover when it is flooded. Stains may leach from woody debris on the impoundment bottom and add more color to the already deeply stained water in acidic northern wetlands. However, all brush need not be eliminated since some woody cover may be desirable. Flooded brush areas sometimes receive good waterfowl use--especially from molting waterfowl which find the brush to be an attractive cover.

Production of 'Greens' for Early Spring Use by Waterfowl

If areas are burned during the dormant period, the annual rough is not only removed, but the area greens up earlier in the spring. There are probably two reasons. First, the overstory of old dead stems is removed and the new plants are released from their shade. Second, the charred and blackened surface absorbs more solar energy and warms the soil for plant growth. Because these areas are free of the usual dense vegetative tangle, they are more attractive for waterfowl use. Seeds from smartweed, burweed and other aquatic and moist soil species are exposed by the burn and are more accessible to waterfowl. This, coupled with the succulent new growth released by the burn, may provide excellent goose grazing. Studies have shown the new growth that follows a burn is more nutritious and more palatable than new shoots produced in an unburned area (Komarek 1965).

Waterfowl Nesting Habitat Improvement

Irregular, patchy burns made on semi-dry sedge grass areas during the dormant season can be used to increase edge effect during the spring nesting season and improve its accessibility to the birds. Cattail cover burned during the winter or fall period when the water is low can become excellent coot nesting in the spring when water covers the stubble. The many isolated small patches of unburned vegetation that remain are ideal as coot nesting sites. This is only true if the area is well flooded in the spring.

Effects of Fire

Studies have shown that fire produces more nutritious and palatable forage than is produced in unburned areas. The many seeds, which are normally present in the rank cover, are made more readily available to waterfowl. In general, flower and fruit production may greatly increase in the perennial cover that was burned off. At the same time, there may be a release of smartweed and millet seedlings which produce more abundantly in the burned area. Cotton grass, which provides desirable goose pasture in some northern areas, has been known to increase and flower heavily following an early spring fire (Linde 1969).

Fire is an ancient management tool. The Indians burned the prairies regularly to make travel easier, flush out game and produce desirable food plants.

Burning Techniques

Fires may be either low intensity or high intensity. Most fires used in marsh management work will be high intensity fires or very hot fires. Hot fires are needed to produce a relatively clean burn that will carry through sparse, coarse vegetation having low flammability.

Conditions that keep fire intensity at a low level are:

1. High humidity and high fuel moisture content.

2. A backfire moving into a strong wind which beats the flames to the ground.
3. A headfire driven by a relatively strong wind that causes the fire to move so fast that an incomplete burn is obtained.
4. Sparse vegetation of low stem density and flammability.
5. Cold air temperatures.

Conditions needed for a high intensity fire are:

1. Low to normal humidities and low fuel moisture content.
2. Warm to hot air temperatures.
3. Fuels with high flammability, and high stem density.
4. A very slow-moving backfire moving into a light wind.
5. A head fire moving with a light to moderate wind.

When to Burn

Avoid all burning in the spring nesting period during April, May and June. Early nesting mallards may be present even in the latter part of March in the southern half of Wisconsin. Late summer or early fall burning are best. However, this may cause some conflicts by removing cover on heavily hunted areas. This can be resolved by patch or strip burning these areas so that a portion of the cover remains for hunting. This could be an asset to the hunters since it improves access for hunters in dense areas.

Winter and early spring burns before the ice is out probably conflict the least with other interest but, at the same time, are less effective. Burning cannot be satisfactorily accomplished if there is a heavy snow cover. It must be done in advance of the snows or after most of the snow cover has melted.

CRUSHING AND MOWING

This management practice is not new, but it is not as widely used as it might be. The reason may be that, unless the treatment is carefully timed and executed, the results can be mediocre to poor. It has been principally used to control cattail (Nelson and Dietz 1966), but other species can also be controlled if treated at the proper time during their growth cycle. This practice has been the basis for some cattail control studies in Wisconsin (Linde *et al.* 1976). The results of these studies more closely defined the treatment period in terms of the normal seasonal changes in food reserves of the cattail and related these changes to phenological events.

Types of Injury Imposed

Destruction of Food Reserves

In the southern half of Wisconsin cattail aerial shoots usually begin growing in May and fruiting plants reach their maximum height in the middle of June when the plant is in full flower. During the early period of leaf growth, the plant is drawing heavily on its carbohydrate reserves stored in the rhizomes. These food reserves were produced and stored during the previous growing season. After the crop of new leaves reach full size, they begin to replace carbohydrates in the rhizomes that were used up in leaf production. By the end of the summer there is once again an adequate supply of carbohydrates available to produce shoots during the next growing season. Just before the new leaves begin to produce carbohydrates in excess of their immediate needs, the plant reserves are low and the plant is then most susceptible to injury. If the new shoots are destroyed by crushing, when the carbohydrate reserves are depleted, additional energy will be required to replace them and the plant may be stunted or killed in the process. The degree of kill depends on how accurately the crushing was timed and how effectively the area was crushed.

Crushing should take place during the summer low point in the plant's reserves. The injury will then be most effective. Treating before or after will leave the plants with a greater amount of food energy and the results will be less satisfactory. For field purposes it would be impractical to determine the percentage of carbohydrates present in the rhizomes. However, we know from our studies that the low in food reserves in the hybrid cattail *Typha glauca* is close to the time when the pistillate spathe leaves are being shed and the pistillate spikes have fully emerged. These phenological check points are suitable for use in the field. Plants properly treated at this time should suffer maximum injury. Since individual plants on any particular area vary in their development, it is important to check a representative number of plants. Plants should be treated when most of them are in the desired growth stage, not by the calendar, because weather varies from year to year.

A rolling drum crusher made from a 55-gallon oil drum or an old hot water tank works very well for crushing (Buele 1979). Angle iron cleats are welded at intervals around its perimeter to help crease and crush the leaves. An axle is fastened to the center of the roller at either end. Except for the cleats, the general construction resembles that of an oversize lawn roller. Since the roller is water tight, it can be filled with sufficient water to give it the desired weight for accomplishing the crushing. A medium-sized, all-terrain vehicle (ATV) which has six or more wheels and is

equipped with tracks can be used to pull the crusher drum. Crushing should continue back and forth over the area being crushed until all the stems are completely flattened. If soil conditions are wet or there is some surface water, the crushing is usually more effective. The tops are then ground down into the mud by the crusher and the ATV tracks. This produces more injury to the shoot base and to the rhizome buds which produce the next generation of shoots. Variability in field conditions produces a variability in the results of the crushing. Excellent results can be attained with a single well-timed crushing if field conditions are favorable. However, successive annual crushings are more likely to produce a satisfactory control. Longevity of the openings produced by crushing is influenced by original size of the openings. Small openings quickly grow in due to invasion of cattail from around the periphery. Openings are best constructed as large as practical and peripheral invasion should be treated annually or biennially if permanent openings are to be maintained. Treatment can be made again the following year, when the reserves are at their low point. Treatments in successive years progressively reduce cattail regrowth to little or nothing.

Eliminating the Oxygen Flow to the Rhizomes

It has been established that the leaves of cattail and other emergent aquatics provide oxygen to the rhizome system through the conductive tubes or arenchyma cells (specialized air conducting cells) in the leaves (Classen 1921). This process is in operation throughout the year, even during the winter months after the leaves are dead. The mechanical structure of the leaf does not change after it dies, but continues to provide passageways for air from the surface to move downward to the rhizomes. As long as the leaves project above the surface of the water and are not crushed or sharply bent, they are conducting to the rhizomes. It is obvious, therefore, that if this important air flow to the rhizome is shut off the rhizomes will eventually die. It has been shown that rhizomes can withstand about 2 weeks or anaerobic conditions in the dormant state (Laing 1941). This characteristic of the plant becomes the basis for a control technique. If the leaves and shoots are mowed in the late fall or, on top of the ice in early winter, and the stubble is flooded and remains covered with several or more inches of water until spring, the plant can be killed satisfactorily. Work can be done with a farm tractor and a rotary cutter (Linde 1969). To submerse the cut stems in deep water areas where there is no possibility of increasing water depths further, mowing will have to be done under water. An underwater weed cutter is required (Buele 1979).

Remember that any stems or leaves, either living or dead, that are not cut will be conducting air and the kill will be less in this area. Since the rhizome network extends out into uncut areas, control will be less effective near the edges of the cut area. Oxygen is conducted through the rhizome network for varying distances. This means that it is harder to achieve a kill in the peripheral areas because they are being supplied with oxygen through rhizomes outside the treated area.

HERBICIDES

Use

The principal use of herbicides on Wisconsin wetlands has been for tree and brush control in the wetland basin and on the dikes. Many thousands of acres of lowland trees and brush were sprayed to clear areas for impoundment development and also for opening up areas for sharptail grouse and prairie chicken managment. Herbicides have also been used for cattail control, but on a large scale.

In recent years the popularity of herbicides has declined. Much of this decline can probably be attributed to a greater awareness of the hazards of chemical sprays, tighter state and federal control on their use, and the outlawing of some of the more popular herbicides such as 2-4-5-T. In addition to state and federal controls, there is a moratorium on the use of herbicides in at least one of our field districts in Wisconsin. Use of herbicides must conform with State and federal regulations.

Spray Equipment for Wetlands

Back-pack Sprayers

These are small sprayers of 3 to 5 gallon capacity, intended only for spraying very small areas. They are suitable for spot spraying or touch-up work.

Power Operated Sprayers

Sprayers of this type may have their own power source or they may be operated from the power take-off of the tractor that carries the sprayer. Although the power take-off models have a lower purchase price, they also have the disadvantage of being difficult to calibrate at low tractor speeds. Reducing the tractor speed also reduces the speed of the sprayer pump which then pumps a lower volume of herbicides at a reduced pressure. Tractor speeds are determined in advance, based on the size of the area to be covered and the quantity of herbicide to be applied. If the spray area is small and application rate is large, the tractor speed may need to be slow. At very low tractor speeds, it may be impossible to have sufficient volume and pressure to obtain proper coverage of the spray area.

If the sprayer has a self-contained power source, tractor speeds have no effect on the output of the sprayer pump. This eliminates an undesirable variable and simplifies spraying.

There are a variety of spray nozzles available for use on power sprayers. In Wisconsin, the "T" or Brodjet nozzle has found considerable use in spraying woody sprouts. This is a single cluster of nozzles that spread a fan-shaped spray pattern from either side of the sprayer head. The gun sprayer is used for brush control work where stem density is too great to allow a fixed nozzle spray to penetrate, or where brush is in patches. Gun sprayers are hand held, making it possible to change the spray angle to better penetrate the stem clump and obtain increased coverage.

The mist blower is a special power sprayer with a self-contained power source nad a very high pressure pump. It throws out a vapor-like spray that provides excellent coverage. However, the light weight spray cloud tends to drift and may affect areas where it is not wanted.

Aerial Spraying

This work requires specialized equipment usually obtained by contract. Since aerial spraying is most efficient when large acreages are treated. Costs may be prohibitive on small areas.

Types of Herbicides

Foliar Herbicides

These are compounds that are absorbed through the leaves. To be effective, they must be applied only to actively growing foliage. Vegetation that has been mowed and burned before spraying to eliminate debris must have time to make a good regrowth before it is treated. Foliar sprays must be used carefully so that the vegetation in the sprayed area is not accidentally burned before the herbicide has produced its full effect. Fire immediately after spraying can negate the herbicide effects since the herbicide will be destroyed before it has a chance to be translocated through the plant. This could result in little or no control. Water soluble foliar sprays should remain on the plant at least 6 hours to insure translocation. A rain before this time could reduce control. The most active stage of growth, during food translocation from leaves to stem is the best time for treatment. This occurs as soon as the leaves are fully open and actively growing. Treatments later in the summer, when the leaves are mature and active growth has ceased, will produce poor results since translocation is at a minimum.

In Wisconsin, the foliar sprays Radapon and Amitrol T have produced good results in cattail control. The principal herbicides used for controlling woody vegetation were 2-4-D and 2-4-5-T. These have now been banned because of a health hazard. Tordon, a combination foliar and root spray is a substitute.

Root Absorbed Herbicide

These chemicals are absorbed from the soil and usually act only through the roots, not through foliage (Tordon is an exception). Removing the foliage and ground debris by mowing and then burning allows the herbicide to be more quickly and completely absorbed, with less waste. Moderate rains following treatment soak the chemical into the soil and speed absorption. Rains heavy enough to produce run-off are not desired.

Heavy doses of root absorbed chemicals may affect plant growth for a year or more. Re-invasion of the area is slow, so application rates of the chemicals should be just high enough to do the job.

Examples of root absorbed herbicides are Simazine, Atrazine and Tordon; the liquid formulation of Tordon is a combination root and foliar herbicide which can be persistent. Simazine and Atrazine have ben used only experimentally on Wisconsin wetlands. They tend to persist more than one season if application rates are high. Studies indicated that smartweeds could be released in grass cover by using either Atrazine or Simazine. Mowing and burning before treatment reduced the amount of Simazine needed by two-thirds (Linde 1969: 111). Atrazine use was also less after burning. Smartweeds, however, are somewhat tolerant of Atrazine.

Tordon is also available in pellet form. The pellets are broadcast and their effects slowly released to plant roots by rain. Pellets are effective in controlling brush on dikes.

WETLAND FARMING

Wetland farming can only be used where water is adequate and where the level can be controlled. Control structures must be properly sized and located to permit water to be rapidly removed in the spring for early seeding. If normal tillage practices are to be used, bottom contours must be such that there are a minimum of pools in the planting area where water fails to drain. It is highly desirable to have supplemental dewatering equipment, such as a high capacity propeller pump or a siphon, to speed up dewatering during wet years. For fall reflooding, a dependable source of water with an adequate flow is a necessity. Sufficient water must be available to flood the crop in time to

attract waterfowl during fall migration. If you reflood by pumping, (as often done in sub-impoundments), make sure the pump is dependable and large enough to raise the water levels at the desired rate.

TILLAGE FARMING

Dewatering

Remove water from the impounded area as early in spring as possible so that the soils have sufficient time to drain and dry properly for tillage with conventional farm equipment. The water table should be 12 or more inches below the surface to permit plowing or rotovating.

Tillage

Mechanical tillage is one of the most expensive techniques used in wetland management. Costs vary depending on soil type, effectiveness of water level control, and vegetative cover. In flat, shallow impoundments, the soils may be slow to drain. Above normal precipitation during the spring and summer may cause wet soils to persist into the summer until it is too late to seed a crop that will mature. If the area has never been farmed previously, you'll need a breaker plow or a rotovator to break up the vegetation mat and produce a suitable seed bed.

A variety of plows and other equipment have been used for ground breaking on wetlands in Wisconsin. Breaker flows varied from 18 to 36 inches. They were pulled by crawler tractors that ranged from D-4's to D-8's. In one instance, two D-2 tractors in tandem were used. Such heavy equipment obviously boosts costs. Breaking costs can be reduced or eliminated if new wetlands can be held at full pool for several years to kill the vegetative cover where food patches will be established. This is usually possible if food patches are to be established in sub-impoundments, providing that muskrat tunnelling does not cause problems in the impoundment dikes during high water. If the areas to be farmed cannot be flooded deeply enough to kill existing vegetation, land breaking will be required.

Rotovating is more economical than plowing if the water table is deep enough that the soil will support a heavy farm tractor and rotovator. The rotovator shreds the sod and eliminates the need for discing. A 71-inch rotovator mounted on a 707 International diesel tractor[1] was used in east central Wisconsin (Linde 1969: 80).

Seeding

With mechanical tillage, a conventional grain drill can be used for seeding. This distributes seed more effectively, provides for better seed germination, and is more economical.

MUDFLAT FARMING

Dewatering

Remove water somewhat later than when you use tillage techniques. Mudflats should be wet so that the seeds will settle into the soil surface and germinate better. Seed by mid-June so the crop matures by waterfowl season. A high water table at seeding time usually precludes using a tractor and grain drill.

Hand Seeding by Tractor

A specially modified crawler tractor, known locally as a "mud puppy", was developed in central Wisconsin to eliminate the necessity of walking and using a hand operated cyclone seeder (Linde 1969). Thirty-inch wooden 2- × 4-inch cleats were bolted on the tracks at intervals, effectively supporting the tractor on wet soils. A man standing on a special platform on the rear of the tractor used a cyclone seeder to seed the mudflats.

Wet Seeding

This is a technique presently being used in northwestern Wisconsin to seed Japanese Millet (Wiita 1982). The millet seeds are soaked in water 24 to 36 hours before planting, causing them to sink. While the planting area is still partially dewatered, the wet millet is broadcast by hand from a boat. The seeds lodge in the mud bottom and the remainder of the water is then drawn off. Very few seeds are pulled out of the planting area by the dewatering process. The technique is simple, fast and effective, but is only suitable for use with Japanese millet or other seeds which can tolerate saturated soils and flooding--and which absorb water and sink.

Aerial Seeding

Aerial seeding is probably the most efficient method for a large area. It is quick and effective and not hampered by wet ground, which is desirable for early germination. The prop blast helps drive the seeds into the bottom soils, improving germination. Commercial crop dusting services often have specialized equipment for aerial seeding. To maximize the effect of the propwash and confine the seeded area, flight altitude should be 35 feet (Linde 1969). Narrow bands can be seeded as drawdown progresses over several days.

A conventional light aircraft can be used for seeding if a commercial crop dusting plane is not available. In

[1]*Mention of trade names does not constitute endorsement by the U.S. Department of Agriculture, Forest Service.*

ortheastern Wisconsin a makeshift seeding appara-ıs was made from a piece of stove pipe and a funnel. 'he stove pipe was extended from an opening in the lane while an observer poured seed into the pipe ırough the funnel and the pilot flew 150 feet above round. Results were satisfactory.

Japanese Millet

Japanese millet (*Echinochloa crusgalli*) is undoubt-dly the best food crop planted on wetlands in Wis-onsin and produces the most consistent and atisfactory results. It is very tolerant of most wetland onditions, being able to germinate and survive in sat-rated soils and even in shallow flooded puddles Linde 1969). It is also tolerant of acid conditions McLain 1957). Japanese millet will continue to grow nder flooded conditions as long as the leaves are bove the surface. This allows it to be flooded well efore the plant is mature--a positive trait in northern reas where early frosts are common. Flooding to pre-ent frost damage is, of course, a well-known part of ranberry culture. Because of the residual heat in bod-es of water covering flooded areas, frosts must be se-ere before they will damage millet crops growing nder flooded conditions. However, early flooding may ause problems. Waterfowl work back into the flooded reas and walk the plants down to get to the seeds. n early maturing crop that is flooded may be used p well before the waterfowl season begins if the crop small. If the planting is large, there may be sufficient ood available through the season despite its early use. everal plantings made at intervals can provide a con-nuing supply of food, as long as flooding is also pro-ressive so that all the crop is not exposed to bird use t one time. This method keeps birds out of the late lantings until they are matured and have been ooded. It spreads use of the crop out over a much nger period of time than if the entire area was lanted with one seeding and flooded as a single unit.

eer Damage

Deer graze the young seedlings and may also feed n the mature seed heads. If the planted area is small, he entire crop may be destroyed. Rye fields planted ear millet have been successfully used to divert deer om the millet (McLain 1957).

lackbird Damage

Blackbirds can also be troublesome in millet plant-gs, but if the planted area is large enough, usually here is sufficient seed produced to feed both the ackbirds and the waterfowl. Blackbirds knock many eeds into the water and these are still available for aterfowl use. In southeastern Wisconsin seeds asted by feeding birds may be sufficient to produce a sizable second year crop, without additional seeding. In the north, second year crops are rare.

Other Millets

Proso, Browntop, and German millets have all been used as waterfowl food crops in impoundments in Wis-consin with poor results. All of these species are sus-ceptible to water and frost damage and will not tolerate flooding. So they can only be used in places where the usual tillage practices are possible. They cannot be flooded until they mature. There seems to be no advantage in using these species since Japanese millet is far more tolerant and productive under wet-land conditions.

Smartweeds

Smartweeds are common invaders of mudflats in Wisconsin. They are tolerant of wet soil, flooding, frosts (often maturing after the first frost), and of great value to waterfowl as food, One of the most pro-lific and widespread smartweeds is *Polygonum lapa-thifolium.*

Smartweeds need mudflats by late May or June, on which to germinate and develop. They may be seeded before this time either naturally or by planting. The seed will germinate after the surface soil begins to dry. After frosts have dried the plants, waterfowl begin to use them heavily.

When both Japanese millet and smartweed are pres-ent, waterfowl use the millet first and then the smart-weeds (Linde 1969). Seeding of smartweed may be war-ranted in northern Wisconsin, where the season is too short to plant Japanese millet, but seeding is seldom needed in the southern half of the State. Natural seed-ing of smartweed is adequate in the South.

Buckwheat

Buckwheat (*Fagopyrum sagittatum*) has been one of the more preferred wildlife foods planted in Wisconsin wetlands. A short-maturing variety such as "Duck wheat" has high yields and is less susceptible to frost damage than other varieties. It grows better on poorer soils and sets seed under more adverse conditions than other buckwheat varieties (Stanton 1957).

Good crops of buckwheat are obtained on drained bottomlands if allowed to mature before flooding and frosts. The average date for seeding buckwheat in Wis-consin wetlands is the 26th of June (2 weeks later than Japanese millet) (Linde 1969). Mechanical tillage is usually used and the seeds are drilled in. Seeding in northern Wisconsin should probably be about 3 weeks earlier to avoid early fall or late summer frosts. Buck-

wheat can be hand seeded on mud flats in small wetlands, but it is also well adapted to tillage.

Since the growing season in Wisconsin varies from 30 days in parts of the northeast to 140 days in the southeast, planting dates will need to be adjusted according to local conditions. Generally the northern half of the State is about 3 weeks behind the southern half, but there are many exceptions to this statement. Plant according to local planting rules.

REFLOODING

Timing is important. If flooding begins too early, the food crop may be utilized before the hunting season opens. The area will have lost its attractiveness to waterfowl and will not hold them through the hunting season. If reflooding begins too late, the birds will not have established use patterns before they are disturbed by hunting, so they may not stay.

If the area is large enough, and bottom contours are suitably variable, the crop can be made available to the birds in stages by gradually flooding the planted area. Seeding at intervals in the spring, combined with progressive flooding in the fall, can provide food through the entire waterfowl season if the planting is large enough.

In west central Wisconsin, where several hundred acres of Japanese millet were seeded and another 500 acres of smartweeds were produced, progressive flooding made available from late summer through fall sufficient food to more than supply all waterfowl needs.

MODIFYING SEMI-DRY WETLANDS TO INCREASE WILDLIFE USE

Potholes

Wetlands frequently have relatively large areas of semi-dry sedge-grass meadows around the edges. These areas are a normal part of the wetland and may be important in storing nutrients and filtering out suspended materials when flows are strong. How can we make them more productive for wildlife? In many cases--by building potholes. The sedge-grass cover provides waterfowl nesting habitat, but the important small water areas needed for breeding pairs is lacking. By constructing a series of small potholes in the sedge-grass meadows, we have not destroyed the meadow, but merely added another dimension to it--open water. The meadow can still filter and store nutrients, but now it also provides habitat for breeding waterfowl, and is more useful for other wildlife such as deer, raccoon, mink, and marsh birds.

Wisconsin game managers have used this technique on various methods throughout the State. In many cases, the results have been highly satisfactory. In portions of the State where waterfowl breeding populations are normally high, the potholes were readily used and results were good. However, in places where other bird populations were present, this additional habitat was used to a lesser extent. Apparently bird populations must increase in these areas before this additional habitat will be fully used.

Potholes should be located within the normal traveling range of breeding pairs as they move to and from the larger open-water areas of the marsh. Consider locating potholes near waterfowl brooding areas such as a deep-water marsh, a stream or river, or a large ditch or pond. Brood areas can be constructed, if there are none nearby. Although waterfowl are known to travel with their broods one to two miles or more to suitable brood water (Evans and Black 1956), the closer they are, the fewer the chances of predation.

In Wisconsin, excavated potholes (bulldozed or dragline) are rectangular and most commonly--about 15 to 20 feet wide, 40 to 60 feet long, and about 4 to 5 feet deep. Bottom contours generally include two shallow edges sloping to a deeper center; the opposite two sides are steep. The shallow edges provide the conditions desired for puddle ducks and the two steep edges reduce the encroachment of emergent vegetation into the pothole. Optimum spacing is about 200 feet (Hammond and Lacy 1959). Grouping the potholes in a block pattern is desirable. Excavated potholes get more bird use than blasted potholes, but they are more expensive as well.

Bulldozed Potholes

These can be economical, accurately contoured, and have well shaped spoil banks if bulldozed in dry to moist mineral soils. Most bulldozer work occurs in the northern part of the State where mineral soils are more common.

Dragline Potholes

If the water table is on the surface, the dragline is more practical to use. It can be operated on supporting log mats when the soils become too soft to support its weight. Mats must be moved before the dragline can move to a new location; this necessarily slows up production and increases costs. The dragline can also operate without mats on a frozen surface. Movement between construction points is then faster, but a steel ball must be used to break the ice and frost layer before the excavation can begin.

A dragline cannot level spoil banks as well as a bull-lozer. Spoil is usually cast in a loose pile along the dge. Bird use seems as good on a pothole with rough poil banks as on one where the spoil is leveled.

Moving a dragline and other heavy equipment in nd out of an area is costly so there must be enough otholes constructed to make the operation cost ef-ective. If the course along which potholes are to be onstructed is "U-" or circle-shaped, it will bring the ragline back to its starting point and increase its fficiency. This will result in it working continuously vith breaks only for moving between potholes.

Blasted Potholes

Potholes have been blasted in both large and small arshes in Wisconsin. ANFO (Ammonium nitrate uel oil mixture) was introduced in the early 1960's Mathiak 1965), and has replaced dynamite. It costs nly 1/10 as much as dynamite and it is considerably afer to handle. A 50-pound bag of ammonium nitrate ertilizer treated with fuel oil is detonated with a stick f dynamite and a standard blasting fuse or electric etonator. This charge will create a hole 19 to 35 feet n diameter and 30 to 72 inches or more deep, de-ending on the soil and water conditions (Mathiak 965). Bottom contours vary from cone- to bowl-haped. Even within the same area, pothole sizes may ary considerably. However, the cost per pothole is uch lower than for any other type of construction.

The bottom of blasted potholes is usually cone-haped and the edges are very steep. Sloughing con-nues for up to 2 years before the bottom stabilizes. hese are not disadvantages if the potholes are con-idered only as breeding pair sites in the spring when ater levels are high. Even if a perpendicular edge is xposed by evaportranspiration in the middle of the ummer, the pothole has already served its purpose or that year as a breeding pair site. More than one air of waterfowl at a time have frequently been ob-erved on blasted potholes in southern Wisconsin. In normal year the potholes remain full of water until arly summer when breeding pair activity is mostly ver.

Blasted potholes are so cheap that new ones can be asted as soon as their short life is over, even on a mited budget. Although small, blasted potholes are ell within the size needed by puddle ducks (Evans *et* . 1952).

Runoff Ponds

Runoff ponds can provide brooding areas on the pe-phery of wetlands. To construct one, place a short dike across an upland drainageway emptying into a marsh. This creates a small impoundment of 1 to 5 acres or more, depending on the edge and drainage contours. If soils are clayey, remove soil from the pond bottom adjacent to the dike. Using a bulldozer, shape and contour the entire deep end of the pond with gradual slopes to provide deep water for diving ducks. Ponds usually contain 6 to 10 feet of water at the deep end. Deep water encourages use by diving ducks; many marshes are too shallow for them.

About 20 acres of cropland or pasture drainage may be needed for each acre of pond (Addy and MacNamara 1948). The drainage area for the pond must be adequate to keep it well filled through the driest part of the summer. Enlist SCS help when planning a pond of this type.

A fixed level spillway is adequate, but it is probably good economy to provide at least a drain tube through the dike so that the pond can be drained for repairs, vegetation control or maintenance. Birds use these ponds more and more after emergent vegetation begins to invade the shallow edges and provides cover. Birds also find safety in the center of the larger ponds.

A CASE HISTORY

In a red clay area in northwest Wisconsin, seepage is minimal so potholes hold water all summer. The game manager constructed one large 2.6-acre pond and 7 small potholes. Dikes were needed only on one large pothole and on the 2.6-acre pond. The remaining potholes were merely deepenings in the drainage area. All were located in a 40-acre grassy field.

Waterfowl response was immediate. In the spring, the potholes were used by breeding pairs and the 2.6-acre pond became a brooding area. During fall migration, geese as well as ducks were attracted to the potholes. Birds flew between these water areas and a nearby privately owned pond.

During the first year, cattail invaded the periphery of the potholes and the pond to provide desirable edge cover. After several years, the cattail spread out into the center of the shallow potholes. In most instances the cover was thin and probably did not interfere too much with bird use. If the potholes had been deeper, cattail would have been restricted to the edges. The edge cover of the large pond appeared to be ideal for broods. Submergent vegetation invaded the large pond, but never became objectionably dense or rank. More potholes of this type may be constructed within a square mile.

Scattered parcels of land unsuited to forestry (but having the right soils and drainage contours) can be

used for constructing potholes and ponds in upland areas. The value of such a complex increases the closer it is to a large wetland.

LEVEL DITCHING

Muskrat Management

These provide open water for wildlife in shallow semi-dry areas. Level ditches are closed at either end so that they do not drain the wetland. Ditches have been widely used to provide year round habitat for muskrats in semi-dry marsh areas (Mathiak and Linde 1956). Spoil banks serve as den sites for the muskrats. If the ditch is connected with deeper areas, where there is a good supply of cattail or other foods plants, the ditch can be very productive. Water depth should be 4 to 6 feet to provide adequate water through winter. Ditches constructed for muskrat management have been 13 feet wide at the surface, 5 feet deep and 5 feet wide at the base (Mathiak and Linde 1956). Zig-zag ditches are recommended and spoil banks should alternate on either side of the ditch. A zig-zag pattern appears to provide more cover for waterfowl. Alternating spoil banks break up predator lanes to some degree, but are probably not truly deterrent in this respect in semi-dry areas. Space ditches about 200 feet apart.

Firebreaks

Level ditching can be used as a firebreak if it parallels the upland edge of the area to be protected. If the spoil is peat, place spoil banks on the outside of the ditch away from the burn to prevent the banks from burning during a hot fire. These firebreaks are still useful for waterfowl and muskrats and other wildlife.

Waterfowl Brooding Areas

Level ditches may be used to lead waterfowl broods away from the grass nesting areas to safer habitat in the deeper parts of the marsh. If level ditching is constructed specifically to serve as a brooding area, the ditch should be at least 30 feet wide at the surface and zig-zag to provide more edge (Mendall 1958).

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WATER QUALITY AND NUTRIENT DYNAMICS IN SHALLOW WATER IMPOUNDMENTS

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The quality of water in shallow water impoundments is principally a function of water source. The three categories of water sources are: surface water only, about equal mixes of surface and groundwater, and mostly groundwater. These categories are typical of the northern Lake States (and presumably adjacent Canada). Other regions near ocean coasts, in semi-arid areas, and in areas with different rock types will have different proportions of dissolved material in their water, but the water sources are the same and the basic principles of water quality in shallow impoundments discussed below will hold in these regions, too.

The purpose of the present paper is to: 1) show how water quality is a function of natural circumstances; 2) compare 5-year, year-around measurements of water quality on seven impoundments, four free-flowing streams, and a natural marsh on the Chippewa National Forest in north central Minnesota (two or three impoundments in each of three water source categories were studied and matched with one or two free-flowing streams in each category); 3) evaluate water quality in terms of State standards for recreation or fisheries; and 4) examine the impact of impoundment aging and drawdowns on water quality.

WATER TEMPERATURE

The annual water temperature range for four control sites (1975-1978) is illustrated in figure 1. From mid-November through March, water temperatures (measured through the ice) were either 0 or 1° C (winter is defined by water temperatures of 0 to 3° C; summer is defined by water temperatures 4° C and higher). Water temperatures from early April through early November paralleled and varied about the mean monthly air temperature as depicted by the dots in figure 1. Air and water temperatures usually reach an annual high in July about 3 to 4 weeks after solar radiation peaks on June 22. Ice-out can occur anytime in April, and ice-up can occur from late October to mid-November.

Water can warm quickly in May and come close to annual highs in response to warm air masses from the southwest and Gulf of Mexico. Water can cool nearly as quickly in June in response to Arctic air masses from Canada. While the range of temperatures in figure 1 represents four different control (natural) sites lumped together, it is not unusual for a single site (natural or impounded) to have a 10 to 15° range in temperatures over the years for a given month. Water temperature variability is greatest on the warming side of the year and least during cooling in August, September, and October. The maximum side of the temperature range curve has a conspicuous bump in late October and early November. This is God's gift to the frozen fingers of late season duck hunters. Otherwise we call this the "bluebird days" of Indian summer that result from the last brave advances of warm Gulf Coast air in autumn (fig. 1). In some years, it doesn't occur.

There are differences in the range of water temperatures among natural sites that should be understood before impoundment water temperatures are compared to them. The four natural sites are Turtle Mound Creek, draining a large sand plain with few

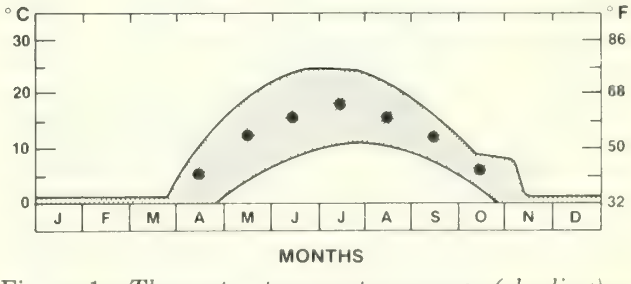

Figure 1.--*The water temperature range (shading) of four natural control sites during a 4-year period (1975-1978) parallels mean monthly air temperature (dots).*

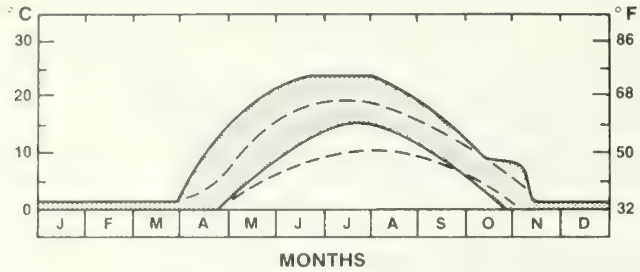

Figure 2.--*The water temperature ranges among controls are separated into those with open water in the drainage (shaded) and a stream without open water areas in the drainage (dashed lines).*

wetlands; Sucker Creek, draining a large area of uplands, wetlands, and a chain of lakes (which are more than a mile across); East Lake Creek which drains a small active beaver area with groundwater springs; and Goose Lake (½ mile long, and classified as a deep freshwater marsh) which receives primarily surface water from a small watershed and has limited outflow.

Water temperatures in Turtle Mound Creek (with no significant surface water areas in the drainage) are consistently cooler by about 5° C than water temperatures at the other sites that have large, open water areas in the drainage. The water temperature in a lake, stream, beaver flowage, and natural deep marsh are similar, but warmer than streams without open water areas in the drainage (fig. 2). Open water areas whether fed by near-surface or deep groundwater sources have similar temperatures that are 5° C warmer than groundwater fed, perennial streams. They also warm slightly faster in April and cool slightly faster in September than streams (fig. 2).

When all impoundment water temperatures are compared to all natural sites with open water, we find that minimum temperatures are identical, but maximum temperatures can rise another 5° C (to 33° C) in July. This additional increase in water-impoundment temperature is not typical, and only occurs in stagnant, diminished pools with no water flow (fig. 3).

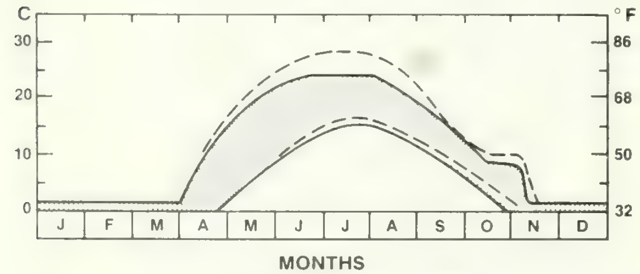

Figure 3.--*The range of impoundment water temperature (dashed lines) is similar to natural open water areas (shaded) for minimum values, but can rise an additional 5° C in stagnant, diminished-pools with no water flow (upper dashed line).*

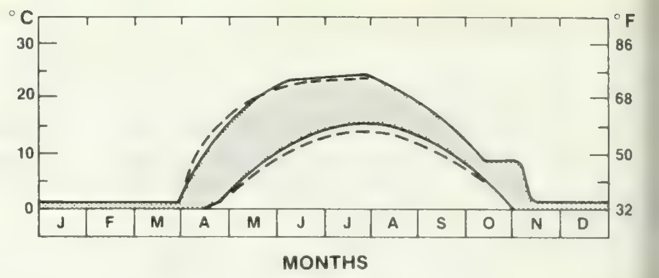

Figure 4.--*The range of water temperature in Ketchum Impoundment (dashed lines) is similar to the nearby Sucker Creek (and lake) (shaded) for groundwater fed areas.*

Ketchum impoundment drains through a quarter mile of stream into Sucker Lake which drains to Sucker Creek where the temperature is measured 100 yards downstream of the lake. All these areas are strongly fed by groundwater, so the ranges in water temperature from Sucker Creek and Ketchum Impoundment are identical (fig. 4). The same is true of Goose Lake (natural deep marsh site) and Cuba Impoundment which are fed by surface water sources and are separated by 35 miles, but this is only true when there is water flowing from the impoundment (fig. 5). The high temperatures depicted in figure 3 occur in diminished impoundment pools (stagnant) caused by purposeful drawdown or dry weather drawdowns in surface water fed impoundments. Table 1 summarizes July water temperature ranges occurring on the Chippewa National Forest.

Impoundment water temperatures exceed 21° C (70° F), which is the maximum temperature for normal trout growth, but maximum temperatures in impoundments with flowing water do not exceed 28° C (82° F), which is below the maximum growth temperatures for northern pike, yellow perch, walleye, small-mouth bass, and sauger (29° C or 84° F), large-mouth bass, bluegill, and crappie (32° C or 90° F), or catfish, white bass, spotted bass, buffalo, carp, and shad (34° C or 93° F).

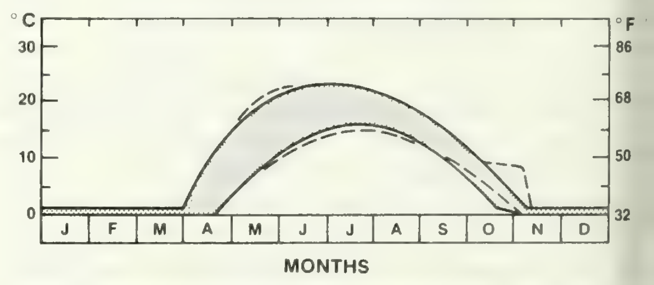

Figure 5.--*The range of water temperature in Cuba Impoundment (dashed lines) is similar to the Goose Lake natural deep marsh some 35 miles to the northeast. Both areas are surface-water fed, but the similarity only holds when there is some water flow.*

Table 1.--*July water temperature ranges on the Chippewa National Forest*

	July water temperature (° C)		
	Maximum	Mid-range	Minumum
Nonflowing, diminished pool impoundments	33	27	22
Flowing lakes, natural marshes and impoundments	28	23	19
Natural streams with little or no open water	23	17	12

Hot water in June, July, and early August can retard fish growth. During these months, the high edge of the water temperature range shown in figure 1 is 8° C warmer than the mean monthly air temperature. Thus an estimate of maximum water temperature in open, flowing water can be made for other locations by adding 8° C to the mean monthly air temperatures in June, July, and August, and an additional 5° C can be added if shallow water impoundments stagnate.

Do impoundments warm their downstream waters too? Very slightly. On a hot day in July with an air temperature of 27.5° C (81° F) we measured a water temperature of 24.5° C (76° F) at the surface of the water impoundment. Within 20 meters (60 feet) of the impoundment outlet, stream temperatures dropped 4° to 20.5 (69° F) and remained at that temperature farther downstream. This drop in temperature occurs because of streamside shading and cooler groundwater entering the stream. The 4° C drop is nearly the same as the 5° C difference between streams (with little or no open water areas in their course) and lakes or impoundments.

DISSOLVED OXYGEN

Shallow impoundments will alter the dynamics of dissolved oxygen from that of unimpounded streams or lakes. Curves delimiting the occurrence of dissolved oxygen in impoundments are depicted in figure 6 for daytime measurements. The upper band from April through November is typical of values found in lakes throughout the year. Shallow impoundments deviate from this pattern in two significant ways.

First, shallow impoundments lose much of their oxygen under ice. When this happens over the long winter (approximately 5 months) a concurrent low redox potential causes a massive migration of nutrients out of the bottom muds and into the overlying waters. In shallow impoundments the layer of enriched waters is no more than 3 to 6 feet--the entire depth of the impoundment. In lakes the cold, mixed waters stay near oxygen saturation over the winter. Data presented by Tonn and Magnuson (1982) confirm low overwinter oxygen levels in northern Wisconsin lakes whose mean depth is 6 feet or less, while deeper lakes exhibit oxygen concentrations over 8 mg/l in January through March.

Secondly, shallow impoundments must handle organic matter surges differently than lakes do. Lakes can pass organic matter into the cool, dark hypolimnion layer. Shallow impoundments do not develop strong thermal stratification as lakes do, thus decay takes place throughout the shallow water. When organic matter is introduced from algae dieoffs, during reflooding over dried organic matter, during concentrations caused by drawdown, and during duckweed die-backs or after leaf-fall, dissolved oxygen concentrations can fluctuate rapidly (principally from June through September). During these conditions, dissolved oxygen will fluctuate from the high range of 5 to 9 mg/l down to the range of 0.5 to 4.4 mg/l (fig. 6).

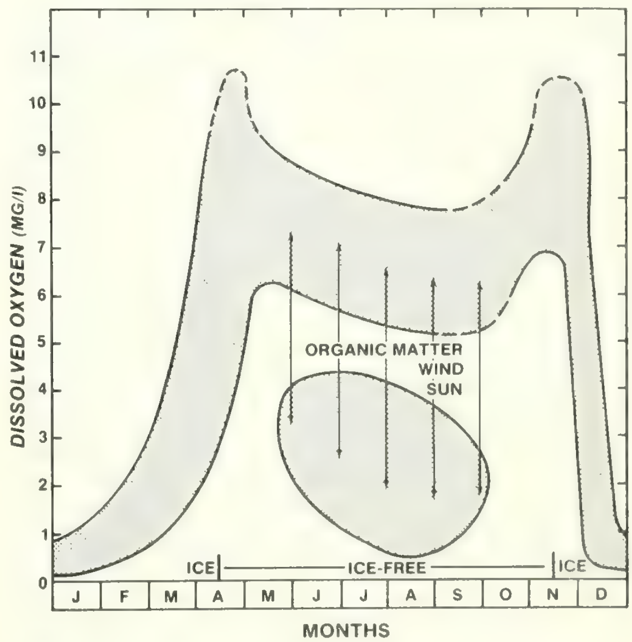

Figure 6.--*Dissolved oxygen in shallow water impoundments (daytime, near surface measurements). During the summer concentrations move between the upper and lower shaded areas rapidly as organic matter is processed and wind mixing or photosynthesis occurs. Dashed lines depict areas of limited data.*

The reduction is caused by the biological oxygen demand of decomposer organisms, but dissolved oxygen concentrations can rebound to higher levels with wind mixing, photosynthesis, and cooler temperatures. Up-down cycles of dissolved oxygen may run for a day or week depending on wind conditions and the amount of dead organic matter. Overnite fluctuations when photosynthesis is reduced can result in similar fluctuations (Lathwell *et al.* 1969).

Shallow impoundments are not well suited for fish populations during the summer or over winter because of these wide fluctuations in dissolved oxygen. The lower dissolved oxygen limits for Class A fisheries and Class B or C fisheries in Minnesota are 7 and 5 mg/l respectively. The spring period (mid-April through May) is not limiting to spawning fish since dissolved oxygen levels average above 5 mg/l, however experimental evidence indicates no loss in maximum swimming speed for northern pike down to levels of 3 mg/l (Adelman and Smith 1970).

TOTAL AND FECAL COLIFORM

Total coliform bacteria populations fluctuate with water temperature; levels are high in summer and low in winter. However, peak total coliform populations tend to lag 3 to 6 weeks behind peak water temperatures (fig. 7). During the ice-free season there is no difference among impounded waters, natural deep marshes, and unimpounded streams; total coliform populations average 900 colonies/100 mls for normal flow conditions. Under no-flow (stagnant water conditions), impoundments and controls both average 5,800 colonies/100 mls. At any single location several samples during the no-flow period exceeded counts of 65,000 colonies/100 ml, our upper limit for actual colony counts. During ice cover, total coliform bacteria persisted at low levels with resting stages capable of multiplying under warm laboratory incubation conditions. Impounded waters averaged 300 colonies/100 ml while all control waters averaged 150 colonies/100 ml. These differences are significantly different at the 10 percent level of confidence but not at the 5 percent level. The differences appear real because the total coliform populations in impounded waters tend to run higher month by month than the controls do (fig. 7). However, throughout the year, total coliform populations measured in all conditions should be considered normal. There are no standards for total coliform except for finished drinking water obtained from deep wells or treated surface waters. Drinking water standards are 1 TC/100 ml.

The numbers of fecal coliform bacteria (colonies/100 ml) run 1000 times lower than total coliforms, but

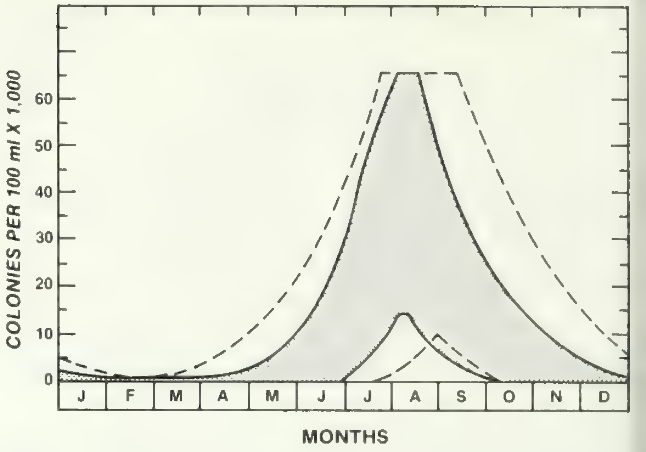

Figure 7.--*Envelope curves showing the seasonal occurrence of total coliform bacteria in nonimpounded controls (shaded) and shallow water impoundments (dashed lines). Truncated tops reflect our too-numerous-to-count limit of 65,000. Three or four values exceeded this at any one location.*

are a direct measure of bacteria from the intestines of warm blooded animals. Fecal coliform bacteria do not follow the slow warming pattern of air temperature as total coliform do. Instead, fecal coliform populations have the ability to explode after ice-out and persist with wide variation until freeze-up (fig. 8).

State standards commonly allow a logarithmic monthly average of no more than 200 colonies/100 ml and no more than 10 percent of individual samples to

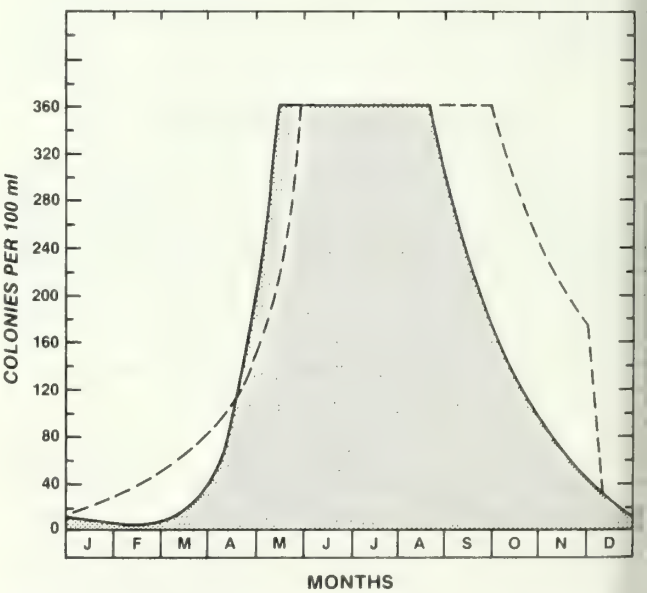

Figure 8.--*Curves showing the seasonal range of fecal coliform bacteria in nonimpounded controls (shaded) and in a range of shallow water impoundments (dashed lines). Truncated tops reflect our too-numerous-to-count limit of 360. Three or four values exceed this at any one location.*

xceed 400 colonies/100 ml for all classes of State aters. There are no significant differences between npoundment and control waters. Fecal coliform populations average 3 colonies (per 100 ml) during winter onditions, 8 colonies during summer-normal flow onditions, and 68 colonies during summer-stagnant onditions. Twelve samples out of 529 or 2 percent ere greater than 400 colonies per 100 ml. Seven of nese occurred on control areas and five on impoundment areas during extremely dry conditions. These ecal coliform levels occur with waterfowl populations t seven per acre or less; over-use by waterfowl can ramatically increase fecal coliform and disease organism levels (Hussong *et al.* 1979).

OTHER WATER QUALITY PARAMETERS

Temperature, dissolved oxygen, and coliform bacteria are strongly related to time of the year, but are ot strongly related to water source. Other water quality measures are. High specific conductance, alkalinity, dissolved solids, and calcium plus magnesium, ndicate groundwater entering an impoundment area. s values of these measures increase, the more groundater volume there is, and the deeper and longer roundwater has traveled to reach and surface at the npoundment site (see fig. 2, Verry 1984). These measres of water quality are highly inter-correlated in the Northern Lake State Region; any one can be predicted rom another.

Color, nitrogen, phosphorus, potassium, iron, and nanganese are primarily associated with organic maerial and tend to cycle over and over through the root ptake, living tissue, plant decay, and leaching pathays. Though relationships are weak, high values tend o indicate surface water flowing through the organic nd A horizons of surrounding mineral soils or through rganic soils in wetlands.

Water pH values can fluctuate widely (1-2 units) nd will not on any given day indicate the degree of nixing between surface and groundwater sources. Many measurements tend to show a slight positive orrelation between pH and large groundwater input, ut pH should not be considered a diagnostic tool for valuating water source.

Impounding water in shallow wildlife production reas will cause only minor changes in summertime ater quality if water levels and flow are near normal onditions. Normal flow occurs when water levels are 5 cm (30 inches) above or below the normal pool levation. Stagnant water (levels more than 75 cm below normal pool) can increase color and nitrogen, but they do not travel out of the impoundment or pose a threat to downstream water quality.

In winter, nutrients increase greatly in shallow impoundments (unlike in most lakes). Even though the increased concentrations are large (2 to 9 times summer levels), they remain within eutrophication standards, but exceed (during most of the year) convenience standards. Because outflow is limited in the winter, impoundments do not pose a threat to downstream water quality.

Mean concentrations will be shown for each water quality measure according to two classifications. One classification is based on season of the year for impoundments: W for winter, SN for summer-normal flow and SS for summer-stagnant. In many cases there is no difference between SN and SS and thus the summer period is shown only as S. Control locations (C) consisting of unimpounded streams or deep marshes (over 3 meters or 10 feet deep) did not show seasonal differences. Winter is any sample taken when the water temperatures are 0 to 3° C; summer when the water is above 3° C. In the second classification, specific conductance was used to group information into three water source categories. They are identified by the mean specific conductance value during summer-normal flow conditions. They are: 70 micromhos (surface water dominated impoundment), 140 micromhos (about equal volumes of surface and groundwater), and 287 micromhos (groundwater dominated impoundments). Standards applicable to fisheries, drinking water, livestock, or convenience are discussed where appropriate.

pH

Impoundment pH values are not different from control values ($\alpha = 0.05$) nor are seasons different. Summer values tend to increase slightly from low to high specific conductance groups (70:6.1, 140:6.3, 287:6.5). Both surface water only impoundments (70) and equal mixture impoundments (140) are below recommended pH levels for all types of fish; thus they are not suited for year-round fisheries (fig. 9). Spring-time spawning areas operated on a net-grow-and-flush basis are an exception to this. Groundwater dominated impoundments have pH levels acceptable to all fish species. For these areas consider the impact of unpassable dams on natural spawning runs.

Specific Conductance

Specific conductance (corrected to 25° C) is easily measured with a meter in the field or laboratory and indicates the amount of groundwater inflow. Because

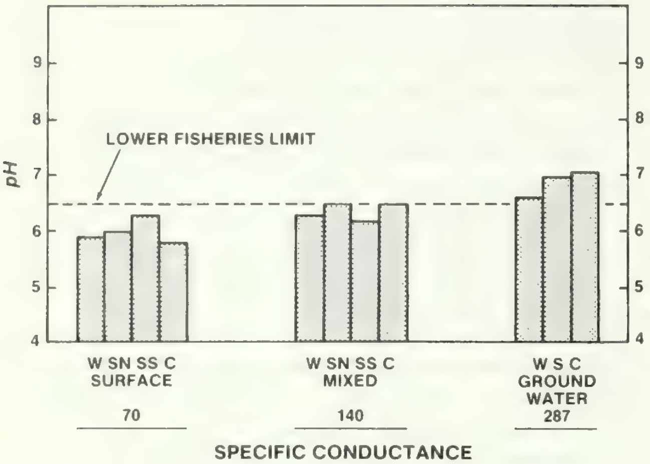

Figure 9.--*pH means in impoundments during winter (W), summer-normal flow (SN), and summer-stagnant (SS) conditions; and nonimpounded control areas in all seasons (C). The three groups of data represent impoundments with different water sources. These are indexed on specific conductance values at summer-normal conditions: surface water only (70), an equal mixture of surface and groundwater (140), and groundwater dominated (287). Bars shaded the same are statistically equal at the 95 percent level of confidence within conductance groups.*

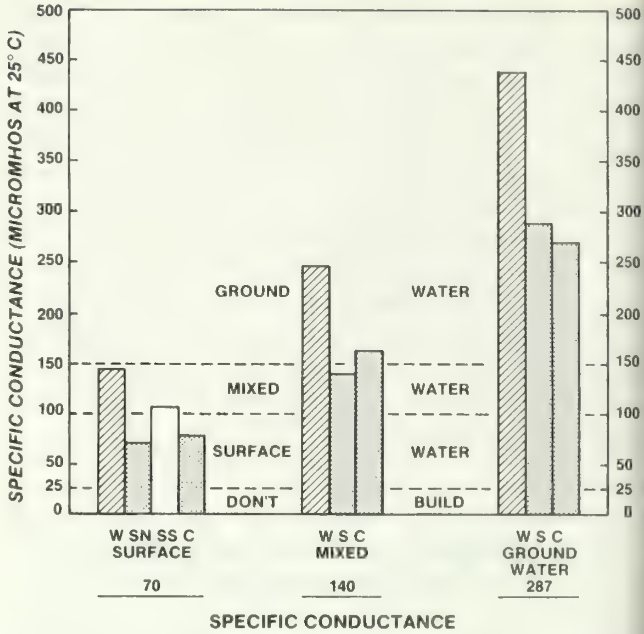

Figure 10.--*Specific conductance means in impoundments during winter (W), summer-normal flow (SN), and summer-stagnant (SS) conditions; and nonimpounded controls (C). Water source labels refer to site selection criteria (Verry 1984). See figure 9 for an explanation of data groups and bar markings.*

of this, it has been selected as a base for comparing water quality in impoundments and for selecting impoundment sites. Figure 10 shows the summer means for specific conductance used to group data on the breaking points used to describe an impoundment's water source. Note the large increases in winter values in all three groups. A similar pattern exists for the other water quality characteristics that are positively associated with groundwater. Correlations of specific conductance with total dissolved solids, total alkalinity, and calcium + magnesium and their corresponding break-points for water source are shown graphically in figures 11, 12, and 13. Note the very low levels of calcium + magnesium and total alkalinity at the do-not-build limit of 25 micromhos. Any of these characteristics can be used interchangeably in the northern Lake States. Regressions of these characteristics against specific conductance may not hold in other areas. For instance, the relationship with Ca + Mg may have a lower slope if another cation such as Na or K is a relatively large part of the cation load.

Because specific conductance is the basis for site selection and vegetation management, one should be aware of the number of samples needed to accurately estimate specific conductance--especially in the 0 to 150 range. Table 2 lists the number of samples needed to estimate within three confidence limits and two confidence levels. Two or three samples will suffice in most instances. With experience and recognition of seasonal flow levels, one will do.

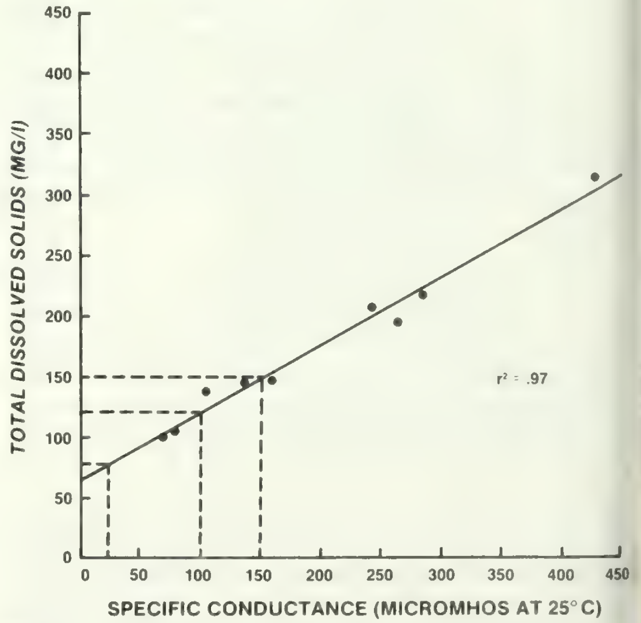

Figure 11.--*The correlation of total dissolved solids and specific conductance; dashed lines refer to site selection criteria based on water source.*

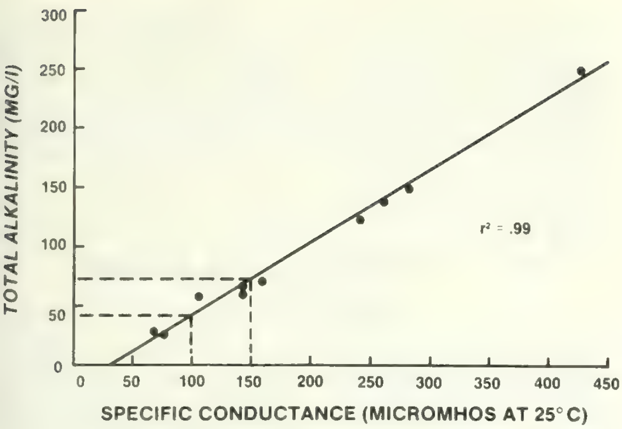

Figure 12.--*The correlation of total alkalinity and specific conductance; dashed lines refer to site selection criteria based on water source.*

Organic Matter

Water constituents derived mostly from organic matter have their concentration levels defined in figures 14 and 15. Again, concentrations are highest in the winter. In most instances, control and summer values are the same. Exceptions occur in apparent color under low flow conditions where the contributing watershed contains organic soils along the side of the inflowing stream. Total nitrogen can also increase in surface water impoundments during stagnant conditions.

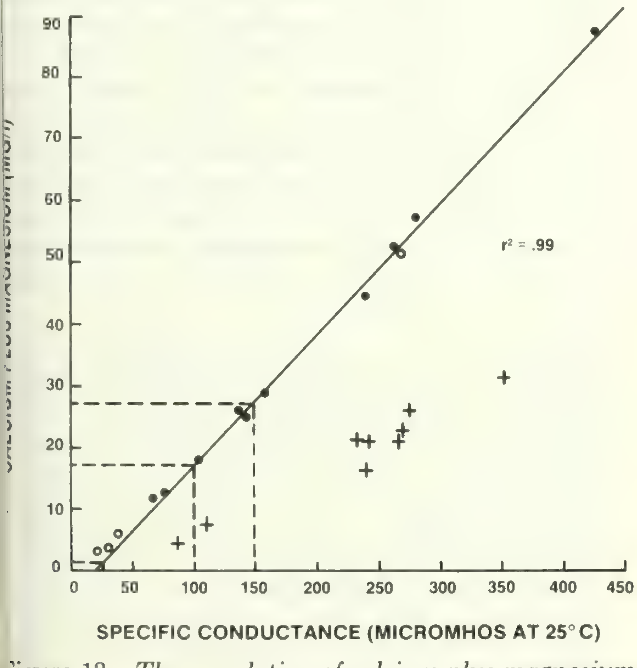

Figure 13.--*The correlation of calcium plus magnesium and specific conductance. Dashed lines refer to site selection criteria based on water source. Solid dots are regression data developed in north central Minnesota. Open circles confirm the relationship at Necedah, Wisconsin (Baldassare 1978) and Backus Lake, Michigan (Kadlec 1962). X's are data from Reid (1982) for Missouri indicating that another cation (probably sodium) is as important as calcium plus magnesium in that region.*

Table 2.--*Number of samples needed to adequately sample specific conductance during normal flow conditions in summer*

	Confidence levels	
Confidence limits	95 percent	90 percent
± 10 micromhos	8	6
± 15 micromhos	4	2
± 20 micromhos	2	1

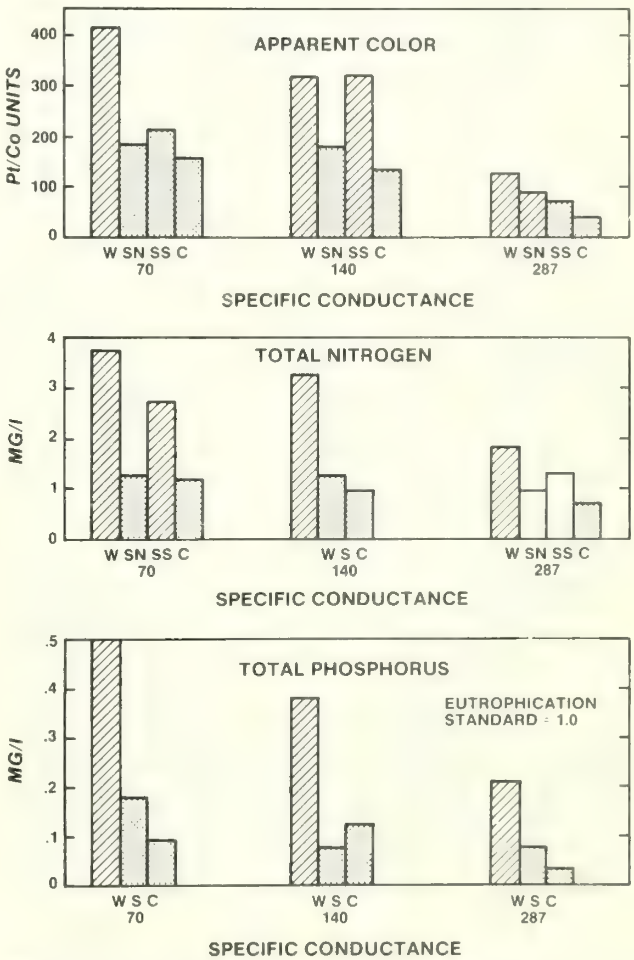

Figure 14.--*The occurrence of apparent color, total nitrogen and total phosphorus means in impoundments during winter (W), summer-normal flow (SN), and summer-stagnant (SS) conditions; and nonimpounded controls (C). See figure 9 for an explanation of data groups and bar markings.*

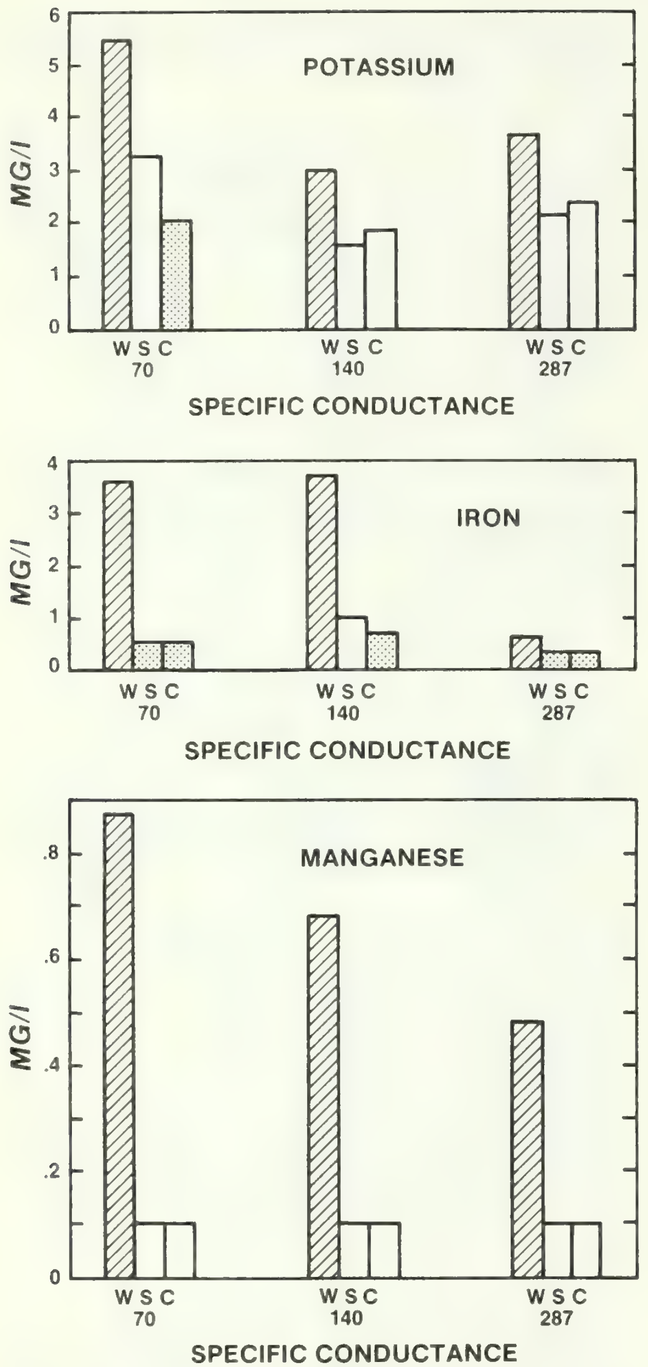

Figure 15.--*The occurrence of potassium, iron and manganese means in impoundments during winter (W), and summer (S) conditions; and nonimpounded controls (C). See figure 9 for an explanation of data groups and bar markings.*

Potassium is easily leached from plant tissue and thus is high in the surface water (70) impoundments, but in strong groundwater-fed (287) areas it can also originate from aquifer rocks. Color, iron, and manganese standards for domestic use are 15, 0.3, and 0.05 mg/l respectively, and are always exceeded, but these standards relate to the taste of coffee made from this water and the brightness of clothes washed in it. The eutrophication standard for total phosphorus is 1 mg/l which is set for receiving lake waters below sewage treatment plants. Impoundment concentrations remain below this standard.

DRAWDOWNS AND WATER QUALITY

Hartman (1949) and McNamara (1957) observed that waterfowl use peaked soon after flooding new impoundments and then slowly decreased. Kadlec (1962) concluded that: "clearly these older unproductive impoundments need rejuvenating." Having observed changes in waterfowl use, several authors sought to show that the underlying causes were at the impoundment site (dismissing any coincidental fluctuations in continental waterfowl populations). Hartman (1949) believed the basic cause was the exhaustion or unavailability of soil nutrients. Cook and Powers (1958) found that soil nutrients accumulated after flooding, but thought that iron or manganese in soil solutions might reach concentrations toxic to plants with time. Kadlec (1962) concluded that: "soil and water analyses indicate a definite increase in plant nutrients" during and soon after reflooding in a Michigan impoundment. Whitman (1976) in summarizing Kadlec's work wrote, "He attributed the high levels of dissolved nutrients, which occurred shortly after flooding, to a rapid release of soluble nutrients from the substrate and the pre-flood terrestrial vegetation. Subsequent declines resulted as the nutrients were reduced by developing flora and fauna or became trapped by the colloidal content of the substrate."

In Whitman's own analysis of impoundments near the New Brunswick-Nova Scotia border, he showed that impoundment fertility (water chemistry) decreased with age. From an age of 6 months to 7 years alkalinities declined from 32 to 16 mg/l $CaCO_3$, specific conductance from 260 to 86, but calcium at 3 mg/l was relatively stable. Thus over the lst 25 to 30 years the literature has shown the importance of drawdowns for maintaining productivity in waterfowl production areas, and has attributed lower productivity with age to the loss of nutrients.

Drawdowns can be a useful tool for increasing waterfowl use in some impoundments; however, the loss of productivity in aging freshwater impoundments being *caused by nutrient loss is an incorrect concept.*

Let's re-examine the evidence. Whitman's (1976) age-fertility decline also showed chloride declining from 62 to 14 mg/l and sodium declining from 34 to 10 mg/l. He failed to recognize the importance of water

ource at his study areas. Sodium and chloride were he major cation and anion in solution and occurred t the ratio of 1:1.8. Since this study was located in ne Maritime Provinces of Canada, the source of such rge concentrations of sodium and chloride can only e sea salt (sea water has a Na:Cl ratio of 1:1.8). I can nly conclude that the selection of impoundment age ategories was, unfortunately, positively correlated ith distance from the Atlantic Ocean.

Kadlec's data was based on 24 samples, only 2 to 6 f them were taken in pre-drawdown, drawdown, or efilled conditions. Though he undoubtedly measured ifferences, the variability of all 24 samples is well ithin 2 standard deviations of the summer means hown for comparable nutrients in figures 13-15. Kad-ec (1962), as a result of his own work at Backus Lake, Iichigan, and in his consideration of DiAngelo's mas-er thesis (1953) on plant succession after flooding rojects in Michigan, also concluded that plant succes-ion is responsible for the pattern of waterfowl use. Knighton (1984) defined the important impact of ater level fluctuation (and its dependence on water ource) on plant succession.

To leave this discussion without direct evidence of ne insignificance of drawdowns on nutrient availa-ility would be irresponsible. Many of the misconcep-ons relating to nutrient availability would never have ccurred if water quality studies were conducted year round. Some authors have made winter measure-ents on either dissolved oxygen or alkalinity but ever other nutrients (Lathwell *et al.* 1969, Bouldin *et l.* 1973). The average impact of winter conditions has een illustrated in figures 10, 14 and 15, but the range particular nutrient takes over winter can only be en in time plots. All dissolved constituents in im-oundment water increase over winter with the ex-eption of oxygen, which decreases. The mechanism ausing these increases is associated with a low level f oxygen and caused by a redox potential of 0.2 volts r less. Above a redox potential of 0.2 volts, a thin rown oxidized layer exists at the surface of bottom uds. When the redox potential falls below 0.2 volts e surface muds become reduced, the brown layer rns black, and nutrients dissolve readily into the ater (Mortimer 1941, 1942). Much of the nutrient uctuation in impoundment water during ice-free and e-covered conditions is the result of organic matter teractions with either bacteria or changes in the re-ox potential of the environment. Graphs, over time, f total phosphorus, total particulate phosphorus, ater level, and general levels of dissolved oxygen can e used to describe the processing of organic matter nd nutrients in shallow (less than 2 meters or 6 feet eep) impoundment waters (fig. 16).

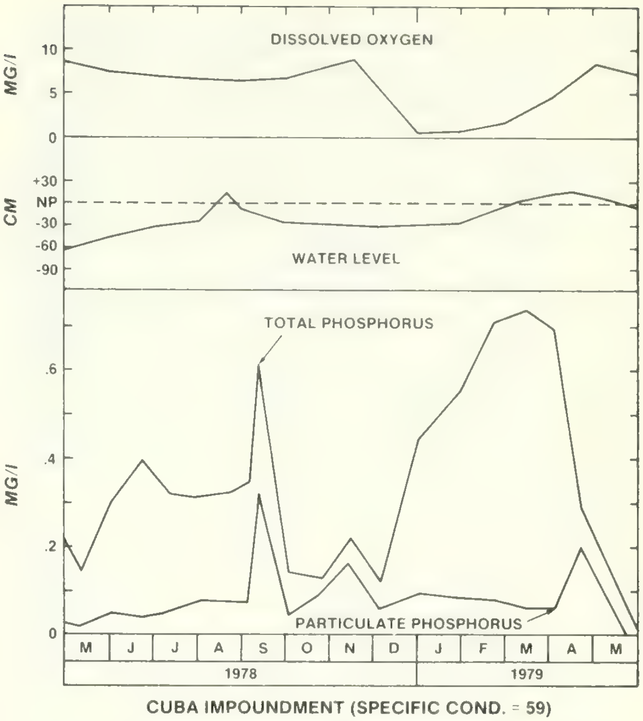

Figure 16.--*Water level, total phosphorus, and total particulate phosphorus in a surface water only shallow water impoundment. The dissolved oxygen is constructed from mean values measured in many impoundments.*

Cuba Impoundment was in a drawdown over the winter of 1977-1978 and was at a water level of 90 cm (3 feet) below normal pool on April 1, 1978. The impoundment filled to normal pool by mid-August. During this time, total and total particulate phosphorus concentrations were not different from summertime values measured under relatively stable water levels. The drawdown and refilling did not affect concentrations of nutrients in the water. During May, June, July, August, and early September, the difference between total and total particulate phosphorus (dissolved phosphorus) was relatively large--a common situation during the summer. In mid-September total and particulate phosphorus levels increased as the result of large organic matter inputs. These inputs probably consisted of a die-off of duckweed and hardwood leaf-fall. Particulate levels remained a relatively large part of total phosphorus during the fall even though oxygen levels increased in the cold waters.

Ice cover was complete by November 15. Oxygen levels began to fall but even during late November and early December bacteria were working hard to consume organic matter. Sometime in late December the bottom muds became reduced (redox $<$ 0.2 volts) at their surface and very large amounts of nutrients dissolved into the water, coated dead vegetation, and kept

rising in concentration into early April. The ice cover broke in mid-April, and in a matter of 1 or 2 days the waters increased in oxygen, redox at the surface muds rose above 0.2 volts and dissolved nutrients precipitated into the bottom muds. In late April and early May the relatively high particulate phosphorus levels indicate that bacteria were facing a challenge to reduce organic matter loading from upland snowmelt, but had mostly overcome these inputs by late May. Similar curves exist for impoundments with large amounts of groundwater input. Although the fall organic matter peaks are smoothed out in the higher flow situation, the over-winter increases are just as large (fig. 17). Ketchum Impoundment was also at 90 cm. (3 feet) below normal pool in mid-November of 1976 and filled over winter from groundwater inflow.

Drawdowns do not affect water nutrient concentrations any more than normal variation during ice-free periods. All impoundment waters recycle mud nutrients into the water at large concentrations under the ice. This occurs in waters 6 feet deep or less under ice cover whether drawdowns occurred previously or not. Thus drawdown techniques should be based on prescribed needs to alter life-form vegetation patterns and plant-water interspersion, and not for the purpose of recycling nutrients.

The previous discussion applies to ice-covered impoundments in forested areas of the northern Lake States, New York, Vermont, New Hampshire, Maine, and adjacent areas of southern Canada. There are large allocthonous (derived from outside of the impoundment) nutrient inputs to impoundments there and elsewhere that were not measured in the relatively undisturbed forested study areas. These include large amounts of salts derived from oceans in maritime zones, rivers flooding water and nutrient-rich sediment into adjacent wetlands, nutrient-rich waters and sediment from agricultural runoff, dust in dry areas, sewage or irrigation water outfalls, and pumping of groundwater of various qualities to fill wetland basins.

All of these conditions may be responsible for filling a drawn-down impoundment, and may be confounded with a perceived nutrient rejuvenation resulting from the drawdown.

Drawdowns and refilling with indigenous water will cause nutrient concentrations to increase in the water as dried muds and decayed vegetation are dissolved. However, the magnitude of these concentration changes must be put in perspective. They are similar to changes occurring with autumn leaf fall, algae or duckweed die-offs, and evaporation concentration. Nutrient concentrations caused by reduced bottom muds are two to nine times larger and they occur every year. Allocthonous nutrient additions may also be on

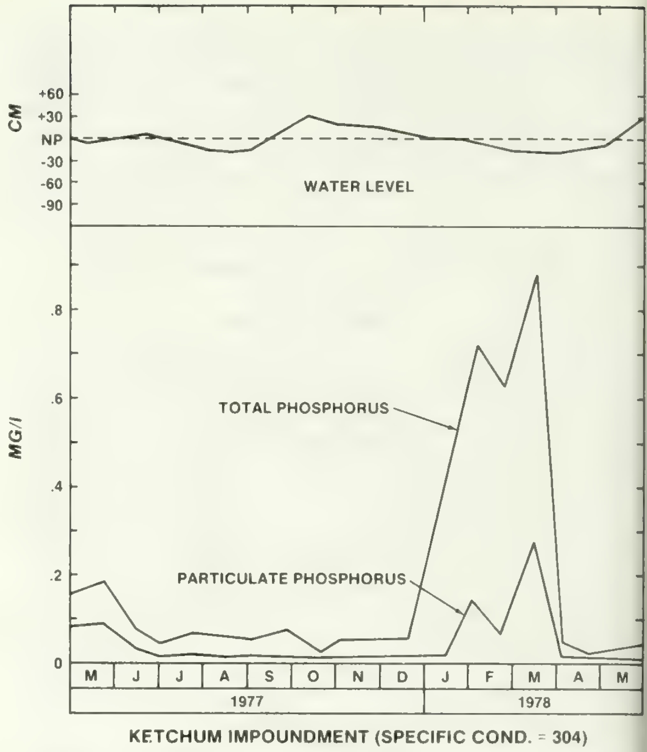

Figure 17.--*Water level, total phosphorus, and total particulate phosphorus in a groundwater dominated shallow water impoundment.*

a scale similar to reduced conditions; both these and reduced mud sources are large compared to drawdown-refilling effects with indigenous water.

SUMMARY

Water chemistry is a good indicator of water source (surface, groundwater, or mixtures) and thus the relative amount of water supply. Impounding shallow water areas up to 2 meters deep will increase July maximum temperatures by 5° C above unimpounded streams, but temperatures will be identical to natural marshes and lakes. Releasing water to shaded streams reduces water temperature by 4° C. Dissolved oxygen (DO) fluctuates from less than one mg/l under the ice to super saturated conditions in the spring and fall. Rapid DO changes during the summer restrict fish use. Neither coliform bacteria nor dissolved nutrients exceed State standards for recreational uses or eutrophication. Drawdowns do not recycle large quantities of nutrients in the water, but reduced bottom muds do release large nutrient amounts every year under the ice regardless of water source or timing of drawdowns. Thus water quality is not justified as a reason for drawdowns, but is related to water supply and variations in water level which control vegetative growth.

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WETLAND INVERTEBRATES IN RELATION TO HYDROLOGY AND WATER CHEMISTRY

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Mosquito control, especially as a restraint to the vector of malaria and encephalitis, was one justification for drainage of North American wetlands in the early 1900's. The decline of yellow fever and malaria after swamp and marsh drainage associated with the Panama Canal project was often cited to defend agricultural "reclamation" of other "wasteland" wetlands (Nolen 1913).

Today the economic, political, recreational, and scientific values of functioning wetland ecosystems are increasingly recognized (Odum 1978). Unfortunately, vast areas of North American natural wetlands have been lost to agricultural, industrial, and urban developments (Weller 1981). Many remaining wetlands have suffered major perturbations in water quality, hydrologic regime, and habitat isolation. A holistic management philosophy for public wetlands has recently been adopted by most natural resource agencies. These long-term management plans often include restoration of certain drained wetlands. Although the ecological functions of natural wetlands cannot be completely duplicated, water impoundments have proven effective in many wetland restoration programs. Monies from license fees and taxes on hunting and fishing equipment have allowed public acquisition of many wetlands by state and federal agencies.

While the general public has a positive attitude toward wetland birds, mammals, herpetofauna, and fish, their interest has not been expanded to include aquatic invertebrates. Many recent studies have demonstrated that these lower trophic forms are extremely important in maintaining a functional wetland habitat, not only as a protein food base for vertebrates, but also in nutrient cycling (Anderson and Sedell 1979). The purpose of this manuscript is to provide resource personnel with ecological information on both wetland invertebrates and, more specifically, how these organisms may respond to wetland management techniques.

INVERTEBRATE ADAPTATIONS TO HYDROLOGIC CHANGES

Long-term, regional hydrologic cycles have shaped the life history strategies that wetland invertebrates have evolved. Short-term water regimes, physical factors (basin morphology and complex structure), chemical factors (nutrient inputs), and biotic factors (hydrophyte structure and predator density) may, however, determine actual occurrence and abundance at any given time. Present knowledge regarding ecological strategies available to temporary pool invertebrates has been well summarized (Wiggins *et al.* 1980). The basic life history groups from that manuscript are summarized using examples of genera (table 1).

Basic invertebrate adaptations for temporary wetlands include rapid development, marked seasonality in life cycle, and egg or pupal stages that can tolerate drought periods. The groups of Turbellaria (flatworms), Lumbriculidae (freshwater worms), Bryozoa (ectoprocts), Anostraca (fairy shrimp), Conchostreaca (clam shrimp), Cladocera (water fleas), Ostracoda (seed shrimp), Ephemeroptera (mayflies), Chaoboridae (phantom midges), Culicidae (mosquitos), and Sciomyzidae (marsh flies) all contain species with drought resistant egg, ephippia, or statoblast stages. Many organisms demonstrate an obligate diapause (period of non-development) which appears tied to seasonal flooding. Eggs of *Caenestheriella* phyllopeds may remain viable for 5 years under dry conditions (Mattox and Velardo 1950). Some midge larvae construct cocoons during dry periods (Grodhaus 1976). Fairy shrimp are dependent on wetland habitats which remain dry in winter, but reflood in spring (Broch 1965). Other adaptations include self-fertilization in some pulmonate snails and parthenogenetic reproduction in cladocera. As reflooding occurs, *Daphnia pulex* may direct a mere 5 percent of its gross energy

Table 1.--*Invertebrate groups according to life history tolerance or avoidance of drought period and period of recruitment in the community (Wiggens* et al. *1980)*

Group 1--Overwintering residents:
Passive dispersal only.
Examples include *Phagocata, Nais, Helobdella, Daphnia, Cyclops, Procambarus, Hyallela, Asellus, Physa, Gyraulus, Sphaerium.*
(Most oligochaetes, leeches, zooplankton, crayfish, amphipods, isopods, gastropods, pelecypods)

Group 2--Overwintering spring recruits:
Oviposition dependent on water; most reproduce in spring water.
Examples include *Agabus, Haliplus, Hydrobius, Tanytarsus, Chironomus, Tabanus.*
(Some beetles, most midges.)

Group 3--Overwintering summer recruits:
Oviposition independent of water; egg deposition in mud.
Examples include *Lestes, Aedes, Chaoborus.*
(Odonates, mosquitoes, phantom midges.)

Group 4--Non-wintering spring migrants:
Adults leave temporary water before drying; overwintering mostly in permanent water.
Examples inlcude *Sigara, Notonecta, Belostoma, Gerris, Ranatra, Dytiscus,* Gyrinus.
(Most hemipterans, some beetles.)

budget (in excess of maintenance) toward growth, but then spend the remainder in reproductive effort (Richman 1958).

Behavioral adaptations to drying conditions may include burrowing in sediments, moving toward deeper water or emigrating from the basin. Leeches, oligochaetes, clams, and crayfish may burrow into the water table to avoid desication. Imago beetles and hemipterans demonstrate well developed flight dispersal in relation to water drawdown (Fernado 1958). This migration strategy requires high energy food for flight and, correspondingly, a reduced fecundity. Physical conditions, such as exposed mudflats or increased prey are necessary for such flight, but behavioral interaction with species that are competitors or predators may influence the timing of these movements. Movements may involve only a short flight within a wetland complex to another basin or may extend 80 km or more (Popham 1964).

Food availability and developmental potential are determined by the extent and duration of flooding. Invertebrates that have adapted to such fluctuating conditions demonstrate diverse trophic and developmental strategies. Figure 1 represents the response of four common freshwater invertebrate genera to five separate annual hydrologic regimes in a mid-latitude North American wetland. None of the represented hydrologic regimes meets all the requirements for all four of these common organisms. The adaptive timing of reproduction is based on genetic potential, physiological condition, and habitat availability. The specificity of a population's breeding schedule varies between species, but a wide range of schedules and high fecundity allow for greater success in a fluctuating aquatic environment.

WATER CHEMISTRY AND INVERTEBRATE-HYDROPHYTE ASSOCIATION

As wetland waters fluctuate, ions and nutrients may concentrate or become dilute. These chemical changes influence the richness of invertebrate species, abundance, growth, and behavior. Temperature and oxygen levels seem to have the most pronounced effects. Temperature directly affects metabolic activity. Timing of molt (voltinism), feeding activity, emergence patterns, and hatching are all influenced by water temperature. Turbellaria require temperatures above 5° C to stimulate egg development and above 8° C for hatching (Young 1974). *Phagocata* (flatworms) will fragment into resistant cysts at high temperatures (Castle 1928).

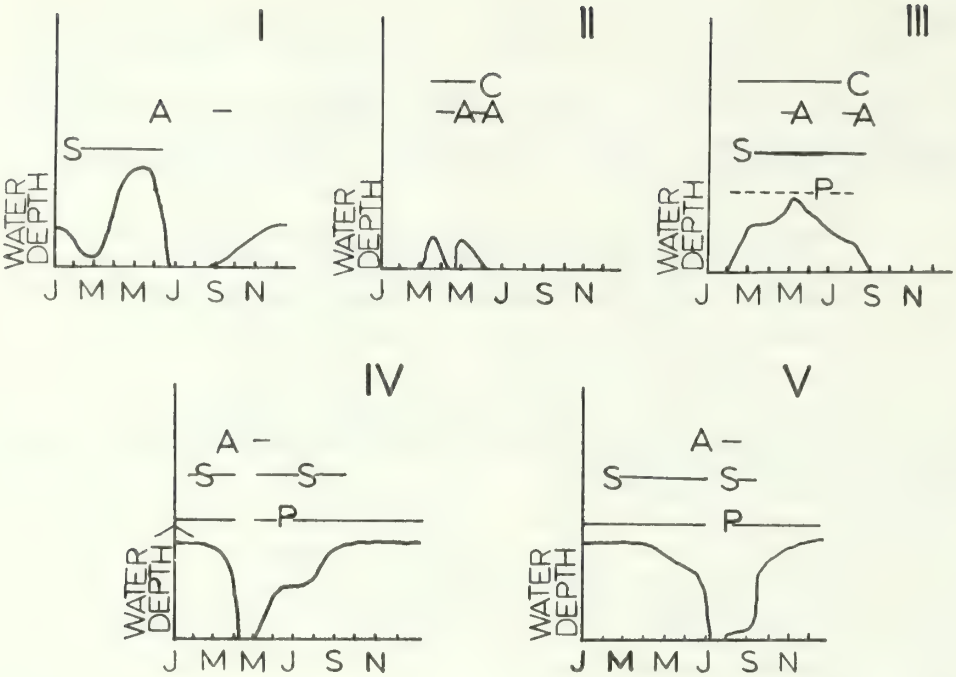

Figure 1.--*Response of four wetland invertebrates (P-*Physa *snail, S-*Sigara *corixid, A-*Aedes *mosquito and C-*Chirocephalopsis *fairy shrimp) to five separate mid-latitude, emergent wetland basins under various annual hydrologic regimes. I-Autumnal Basin, II-Short Vernal Basin, III-Long Vernal Basin, IV-Moist Soil Early Drawdown, V-Moist Soil Late Drawdown. Dashed line indicates occurrence only if pioneering occurs. Letters indicate period of oviposition. (After Wiggens* et al. *1980, Broch 1965, Reid* et al. *in prep.)*

Fairy shrimp are not only dependent on fluctuating water conditions, but fall egg development is stimulated by decreasing temperatures and high oxygen levels. As spring flooding occurs and oxygen levels drop as hydrophytes decompose, the fairy shrimp hatch (Broch 1965). Many other organisms require a strict progression of rising temperatures (Danks 1971). The hatching stimulus for the water flea *Diaptomus stagnalis* is controlled by decreased oxygen levels (Brewer 1964), while the hatching of the playa shrimp *Branchinecta mackini* is controlled by 0_2 tension and percent salinity (Brown and Carpelan 1971). Populations of Molluscs are not large in impoundments in the forested Lake States if calcium and magnesium needed for shell development are low (less than 50 micromhos specific conductance) (Verry, personal communication; Baldassare 1978).

As water fluctuations influence chemical composition of waters, they also influence hydrophyte germination (van der Valk and Davis 1980). One of the earliest recognized habitat relationships for aquatic invertebrates was that with aquatic plants. Hydrophyte leaf shape, structure, and surface area are related to invertebrate abundance (Wieser 1951, Rosine 1955). Several investigators (Krecker 1939, Andrews and Hasler 1943, Krull 1970) have found higher densities of insects associated with aquatic plants containing highly dissected leaves.

Hydrophyte conditions are not stable and changes in growth and senescence influence the invertebrates associated with them. Annual fluctuations in the amphipod *Hyallela azteca* associated with *Chara* and smartweed *Polygonum* can occur, as seen in a shallow Colorado lake (Rosine 1955). The largest standing biomass of invertebrates in Mississippi wetlands occurred in association with coontail *Ceratophyllum* and fanwort *Cabomba* (Teels *et al. 19176).* These submergents become established only after flooding and after resulting turbidity has subsided. Investigations of Lake Erie waters revealed that "thrifty" (or healthy) plants maintain the greatest invertebrate abundance (Krecker 1939). Smartweed leaf drop associated with drought stress and reflooding resulted in a depauparate invertebrate fauna the following spring in a Mississippi River floodplain wetland (Reid *et al.* in prep.).Community composition is dependent on plant condition and food habits of the invertebrates. Seasonal senescence of emergents encourages colonization by detritivore communities (Danell and Sjoberg 1979). Biochemical inhibitors from submergents may

influence associated periphyton (Abdel-Malek 1948) and invertebrate feeding, growth, and hatching. Annual periphyton shifts (Young 1945, Millie 1979) undoubtedly influence grazer community composition.

Despite the wide deversity of species present in most natural or impounded wetlands, certain taxonomic groups are usually dominant. Although techniques and sampling periods vary among studies, chironomids or freshwater worms are usually the most numerous in shallowly flooded emergent wetlands or typical littoral regions of eutrophic lakes (table 2). Dipterans are the most numerous of emerging insects, while mayflies and odonates are somewhat less numerous. In Ontario wetlands 87 and 98 percent of all emerging adult insects were dipterans (Judd 1953, 1958, 1960) and chironomids and culicids dominated the species composition. Snails, mayflies, corixids, and amphipods may form the next most common aquatic groups. Impounded water with minimal hydrologic modifications or shallow lakes may encourage submergent hydrophyte growth and associated amphipods (Cooper 1965, Whitman 1976). Invertebrate production may be less than in seasonally fluctuating wetlands.

Forested wetlands contain a very different community structure than emergent marshes. Fingernail clams *(Sphaerium* and *Musculium)* make up between 58 and 98 percent of invertebrate biomass in Mississippi and Alcovy River floodplain samples (Eckblad *et*

Table 2.--*Dominant macroinvertebrates in selected shallowly flooded, emergent wetlands*[1]

Organisms	Percent of sample	Reported form	Site	Source
Chironomidae	80.1	N[2]	North Slope,	Bergman *et al.*
Oligochaeta	19.9		AK, USA	1977
Gastropoda	36.2	N	Lizard Lake,	Tebo 1955
(Helisoma/Physal)			IA, USA	
Chironomidae	19.1			
Oligochaeta	17.6			
Chironomidae	70.4	N	< 1 yr age	Whitman 1974
Planorbidae	20.3		Managed wetlands	
Corixidae	8.0		NB, CAN	
Chironomidae	42.5	N	1-4 yr age	Whitman 1974
Gastropoda	46.5		Managed wetlands	
Planorbidae	(22.5)			
Physidae	(6.5)			
Lymnaeidae	(17.4)			
Corixidae	6.2			
Chironomidae	61.9	N	7 + yrs	Whitman 1974
Planorbidae	6.2		Managed wetlands	
Corixidae	13.1		NB, CAN	
Talitridae	7.9			
Chironomidae	60.2	N	NB, CAN	Whitman 1974
Planorbidae	9.3			
Corixidae	6.8			
Talitridae	7.0			
Tanytarsus (Chironomidae) + *Hyalella* (Talitridae)	74/54	N/V	S. Michigan Lake MI, USE	Anderson and Hooper 1956

[1]Data does not include zooplankton (Cladocera, Copopoda, Ostracoda).
[2]N = numbers, V = volume.

al. 1977, Parsons and Wharton 1978). *Asellus* isopods, *Cranonyx* amphipods, fingernail clams, and crayfish dominated the invertebrates of lowland hardwood forests of Louisiana, Illinois, and Missouri (Moore 1970, Hubert and Krull 1973, White, 1982).

MANAGEMENT IMPLICATIONS

Although water manipulation is a common tool for wetland management, little is known about its effect on macroinvertebrate ecology (Weller 1978). A dramatic decrease in invertebrate abundance after a drawdown was noted in a Michigan wetland (Kadlec 1962). Herbivores decreased, but predator species increased in another drawdown (Wegener *et al.* 1974). The species diversity of an aquatic invertebrate community dropped rapidly in natural wetlands of Minnesota just prior to drying (Hohman1977). Available biomass during drawdown depends on emigration or aestivation tactics. Most of the information related to drawdown has not considered semi-aquatic organisms such as *Stenus* rove beetles or *Pirata* spiders. These organisms rapidly respond to mudflat conditions and may greatly increase biomass estimates. Response to artificial, shallow flooding is also rapid, especially if timed to natural hydrologic increases and invertebrate growth and hatching strategies. Invertebrate abundance was greatest 6 weeks after Green Tree reflooding (Hubert and Krull 1973).

The duration of flooding influences invertebrate occurrence. Semi-permanent wetlands appeared more productive than seasonal basins in Minnesota (Hohman 1977). Whitman (1974) found 1.5-5 years as optimal for invertebrate production on shallow impounded water of Nova Scotia, while Reinecke (1977) found the greatest abundance and biomass of invertebrates in 3- to 5-year-old beaver ponds. Highly turbid waters will restrict the development of submergents, and if the basin is flooded to depths greater than a few centimeters, the area will rapidly decline in invertebrate usage. Seasonal or semi-seasonal wetlands may be most productive where input waters are highly turbid.

The relationship between invertebrates and vegetation suggests there may be major faunal shifts with vegetation succession. Voights (1976) documented this shift in summer studies of Iowa marshes. Isopod and snail biomasses increased as emergent and dead vegetation increased, while midges cladocera, and copepods dominated more open areas and amphipods increased in dense beds of submerged vegetation. The number of organisms, biomass, and number of taxa all increased when the ratio of cover: water approached 50:50 at the Delta Marsh in Manitoba (Kaminski 1979).

Investigations related to physical treatments (mowing, disking, burning) are few. At the Delta Marsh, mean number of invertebrates was greater on the control site than on mowed or rototilled sites after spring reflooding, but mowed sites showed higher numbers a year later (Kaminski 1979). Density, biomass and taxa richness of aquatic invertebrates increased dramatically 4 weeks after cattails (*Typha latifolia)* were cut and removed from plots in southern Manitoba (Murkih *et al.* 1982). Early fall flooding may produce greater invertebrate numbers in disked areas because of the conditoned plant material (Reid *et al.* in prep.). Most numerous at these sites will be highly mobile aquatic forms (Hydrophilidae, Dytiscidae) or larvae of emergent forms (Culicidae, Ephyridae).

The importance of wetland invertebrates to avain omnivores has been documented only recently (Chura 1961; Sugden 1973; Swanson and Meyer 1973, 1977; Taylor 1977). Because impounded waters are often managed principally for these predators, it is important to know where and how exploitation occurs. The broad term "aquatic invertebrate" has masked the diversity of life history strategies and wetland basins utilized by these prey organisms. Breeding pintails concentrate on chironomids and snails in shallow potholes (Krapu 1974); white-winged scoters feed exclusively on the amphipod *Hyalella azteca* in semi-permanent lakes (Brown 1981); wood ducks eat amphipods, isopods, and snails of lowland hardwood forests (Drobney 1977); while migratory sora feed on semi-aquatic beetles and grasshoppers (Rundle 1980). Variation in emergence and egg laying dates within single insect genera (Meyer and Swanson 1982) allow for potential vertebrate predation over an extended period. Predators may select certain basins because the presence or conditions of plants save as a proximate cue to invertebrate prey. Availability of prey organisms initially increases with decreasing water levels, provided the invertebrates do not emigrate. Predators shift to wetland basins where the least energy is expended to forage.

Invertebrate mortality of 84 percent (Schneider 1978) and up to 90 percent (Schneider and Harrington 1981) has been reported on intertidal mudflats. Wading birds reduced fish biomass by 76 percent in a drying Florida wetland (Kushlan 1976). Invertebrates with low mobility and emigration tactics are most vulnerable when interior marshes dry in mid- to late summer. The behavior of predators may also change (Swanson and Sargent 1972, Watmough 1978) as foraging efficiency increases. Not only the numbers of

prey, but the caloric and nutrient value of prey to the predators should be considered in management options (Driver 1981).

IMPORTANCE AND PROBLEMS OF WETLAND DATA INTERPRETATION

Wetland invertebrates were first considered important in diets of obligate animal predators. Recent food habit studies have shown that invertebrates are highly utilized during critical physiological periods of many vertebrate omnivores. Aquatic invertebrates are also important in vegetative decomposition and processing of nutrients in aquatic systems.

Several problems with wetland invertebrate investigations should be considered when evaluating research for management. Shallow water bodies, often typified by dense stands of emergent vegetation, present a challenge to organism collection. Several techniques have recently been developed or modified (Lammers 1977, Swanson 1978a, 1978b, LeSage and Harrison 1979) by wetland investigators. Different mesh sizes among studies makes direct comparisons of density and production data difficult. The few quantitative studies that deal directly with shallow-impounded wetlands or wetland techniques restrict viable options available to managers. In addition, many of these studies were conducted using broad systematic descriptions of organisims, such that trophic relationships or species life history strategies are impossible to determine. Considering the richness of invertebrate species in wetlands and the myriad of adaptations they employ to deal with water fluctuations, ecological projections based on taxonomic groupings above the level of family or genus are probably suspect.

CONCLUSIONS

Long-term hydrologic cycles have shaped the life history tactics of wetland invertebrates. This diverse group exhibits a wide range of feeding and reproductive strategies in association with dynamic water chemistry and vegetation patterns. The manipulation of water basins will directly influence availability of aquatic habitat and indirectly affect invertebrates through the physiological responses of hydrophytes. Wise, ecologically-based decisions will yield productive wetland systems.

Aquisition of potentially impounded wetlands should favor restoration of natural wetland areas which have been degraded. Construction should emphasize a complex of wetland types which may include green tree and seasonally flooded emergent types. Wetland management should strive to emulate water fluctuations of the region because invertebrates have adapted to such dynamic conditions. The degree and timing of fluctuations depends on desired species composition. Fall flooding will stimulate the hatch of many species and larval forms may continue to develop over the winter. Our present knowledge of water manipulations suggests that management for specific hydrophyte communities may be the most practical means of increasing invertebrate production. A diversity of plants with high seed production, as well as plants with finely dissected leaves may result from integrated management. Inflow water should be monitored for pesticides and pollutants. Management should strive for pesticide education in urban wetland areas because mosquito or agricultural pest control measures may be highly detrimental to wetland invertebrate survival or growth.

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WILDLIFE OCCURRENCE IN WATER IMPOUNDMENTS

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Impoundments can provide valuable wildlife habitat in all parts of the Lake States. They are important in the northern forested region where productive wetland habitats are scarce. In the prairie region they are important during drought years when natural wetlands dry up. They are especially important in agricultural areas where they mitigate the loss of natural wetlands through drainage.

Many species of wildlife benefit from the construction of impoundments. Among these are moose, white-tailed deer, black bear, waterfowl, rails, and common snipe. Whitman (1976) noted that as impoundments were flooded, the waterfowl brood populations on adjacent natural wetlands rapidly decreased. They can be important to endangered, threatened, or sensitive species such as fisher, common loon, bald eagle, and osprey. Impoundments are also used by furbearers or wetland mammals such as red fox, muskrat, raccoon, beaver, river otter, mink, and northern watershrew. Many nongame birds use the impoundments, including waders, raptors, shorebirds, kingfishers, and wetland passerines. In addition, many of the Lake State reptiles and most of the amphibians are associated with wetland habitats (Probst *et al.* 1983, Crider 1979).

A number of studies (Boyer and Devitt 1961, Beule 1979, Whitman 1976) have shown that during the first year after reflooding there is an increase in the density and diversity of birds. These increases can be attributed to increased edge, interspersion, productivity, nest cavities, or perch sites present in the new impoundments. Aerial foragers (bats and birds) benefit from the impoundment openings in forested regions and the abundance of insect prey. Trees, flooded and killed by the impounded waters, provide nest cavities for waterfowl, some mammals, and several passerine birds. Flooded timber and snags provide a foraging substrate for nuthatches, creepers, and woodpeckers and serve as perches for raptors, kingfishers, and insectivorous hawkers such as flycatchers (Probst *et al.* 1983).

Other papers in this workshop will cover specific impoundment management techniques. The purpose of this paper is to describe how wildlife species and groups are affected by various habitat types and management prescriptions.

VERTEBRATE SPECIES OF IMPOUNDMENTS

We divided the Lake States into four geographic regions that broadly correspond to species' ranges. The northern region includes the forests and bogs of northern Minnesota, Wisconsin, the Upper Peninsula of Michigan, and the northern part of lower Michigan. The southern agricultural region of croplands, pastures, and scattered woodlots encompasses the southern halves of Minnesota and Wisconsin. Our third division is the prairie region of western Minnesota where some western species occur. The fourth region is the southern half of lower Michigan which includes the range of several species not found elsewhere in the Lake States. We noted the occurrence of bird species by region and classified each species as either Permanent resident (P), Summer visitor or breeder (S), Migrant (M), or Winter visitor (W). The occurrence of mammals and herpt species are simply noted by region (table 1).

Birds

About 290 species of birds are regularly found in the Lake States either permanently or seasonally. Of these, 100 inhabit wetlands and another 80 or so are attracted to wetland edges. About a dozen species are found only west of the prairie border of Minnesota.

In our survey of 10 impoundments on the Chippewa National Forest (Probst *et al.* 1983) we recorded 138 bird species, 32 of which were not observed by Kirby (1975) on or near beaver flowages in the same forest. The major difference between these studies was the increased diversity and number of shorebirds found in impoundments. This increase was due to the extensive mudflats around managed impoundments in late summer.

Table 1.--*Resident status of vertebrates by geographical region*

Birds	North	South	Prairie	Lower Michigan
+ Com. loon	S	M	M	M
+ Horned grebe	S	M	M	M
+ Eared grebe			S	
+ Pied-billed grebe	S	S	S	S
+ Red-necked grebe	S	M	S	M
+ Western grebe			S	
+ D.C. cormorant	S	M	S	M
+ Whistling swan	M	M		M
+ C. goose	M/S	M/S	M/S	M
+ Black duck	S	W		P
+ Gadwall			S	
+ Mallard	S	P	S/P	P
+ Pintail	M	M	S	M
+ Wigeon	S	M	M	M
+ Wood duck	S	S	S	S
+ Shoveler			S	
+ B. W. teal	S	S	S	S
+ G. W. teal	S	M	S	M
+ Canvasback		M	S	M
+ Redhead		M	S	M
+ Ring-necked duck	S	M	M	M
+ L. scaup	M	M	S	M
+ G. scaup	M	M	M	M
+ C. goldeneye	S	W	-	W
+ Bufflehead	M	M	M	M
+ Ruddy duck			S	
+ C. merganser	S	M	M	M
+ Red-breasted merganser	S	M	M	M
+ Hooded merganser	S	S	S	S
+ Coot	S	S	S	S
+ C. gallinule		S		S
+ White pelican			S	
+ Herring gull	S	M	M	M
+ Ring-billed gull	M	M	local	M
+ Franklins gull			S	
+ Bonapartes gull	M	M	M	M
+ Common tern	S	M	M	M
+ Forsters tern		M	S	M
+ Black tern	S	S	S	S
+ Great blue heron	S	S	S	S
+ Little blue heron		S		S
+ Great egret		S		local
+ Cattle egret		S		local
+ Black-crowned night heron		S	S	S
+ Yellow-crowned night heron		S		local
+ Green heron		S	S	S
+ Least bittern	S	S	S	S
+ Am. bittern	S	S	S	S
+ Sandhill crane		M	M	M

(Table 1 continued next page)

(Table 1 continued)

Birds	North	South	Prairie	Lower Michigan
+ Virginia rail	S	S	S	S
+ King rail		S		S
+ Black rail		S		S
+ Yellow rail	S			
+ Sora	S	S	S	S
+ Avocet			S	
+ Black-bellied plover	M	M	M	M
+ Lesser golden plover	M	M	M	M
+ Ruddy turnstone	M	M	M	M
+ Semi-palmated plover	M	M	M	M
+ Killdeer	S	S	S	S
+ Am. woodcock	S	S		S
+ C. snipe	S	S	S	S
+ S. B. dowitcher	M	M	M	M
+ L. B. dowitcher	M	M	M	M
+ Hudsonian godwit			M	
+ Marbled godwit		M	S	
+ Whimbrel	M	M	M	M
+ Willet		M	M	
+ Greater yellowlegs	M	M	M	M
+ Lesser yellowlegs	M	M	M	M
+ Solitary sandpiper	M	M	M	M
+ Sanderling	M	M	M	M
+ Upland sandpiper	S	S	S	S
+ Buff-breasted sandpiper			M	
+ Pectoral sandpiper	M	M	M	M
+ Stilt sandpiper			M	
+ Dunlin sandpiper	M	M	M	M
+ Spotted sandpiper	S	S	S	S
+ Least sandpiper	M	M	M	M
+ Semi-palmated sandpiper	M	M	M	M
+ Western sandpiper	M	M	M	M
+ White-rumped sandpiper	M	M	M	M
+ Baird's sandpiper			M	
+ Wilson's phalarope		M	S	
+ Northern phalarope	M	M	M	M
Ruffed grouse	P	P	P	P
Ring-necked pheasant		P	P	P
+ N. harrier	S	P	S	P
Red-tailed hawk	S	P	S	P
Red-shouldered hawk		S/P		S
Rough-legged hawk	M	W	W	W
+ Bald eagle	S	W		W
+ Osprey	S	M		S/M
Peregrine falcon	M	M	M	M
Am. kestrel	S	P	S	P
Short-eared owl	S	P	S/P	P
Great-horned owl	P	P	P	P
Barred owl	P	P	P	P

(Table 1 continued next page)

(Table 1 continued)

Birds	North	South	Prairie	Lower Michigan
Great gray owl	P/W			
Snowy owl	W			
Hawk owl	P/W			
C. nighthawk	S	S	S	S
R. T. hummingbird	S	S	S	S
+ B. kingfisher	S	P/S	S	P/S
Red-headed woodpecker	S	P	S	P
Common flicker	S	P	P	P
Red-bellied woodpecker		P		P
Downy woodpecker	P	P	P	P
Hairy woodpecker	P	P	P	P
Black-backed 3-toed woodpecker	P			
Yellow-bellied sapsucker	S	P		P
Pileated woodpecker	P	P		P
E. kingbird	S	S	S	S
W. kingbird			S	
E. phoebe	S	S	S	S
Olive-sided flycatcher	S			
Yellow-bellied flycatcher	S	M		
Willow flycatcher		S	S	S
+ Alder flycatcher	S	M		M
Cliff swallow	S	S	S	S
Barn swallow	S	S	S	S
+ Tree swallow	S	S	S	S
Rough-winged swallow	S	S	S	S
Bank swallow	S	S	S	S
Chimney swift	S	S	S	S
Crow	S	P	P	P
Raven	P			
Gray-jay	P			
White-breasted nuthatch	P	P	P	P
Red-breasted nuthatch	P	W	W	W
Brown creeper	P	W	W	W
Winter wren	S			
+ Long-billed marsh wren	S	S	S	S
+ Short-billed marsh wren	S	S	S	S
Gray catbird	S	S	S	S
N. shrike	W	W		W
Cedar waxwing	P	P		P
Prothonotary warbler		S		S
N. parula warbler	S			
Black-throated blue warbler	S			
Magnolia warbler	S	M		M
Yellow-rumped warbler	S	M		M

(Table 1 continued next page)

(Table 1 continued)

Birds	North	South	Prairie	Lower Michigan
Canada warbler	S	M		M
Chestnut-sided warbler	S	S		S
Bay-breasted warbler	S	M		M
Am. redstart	S	S		S
Prairie warbler				S
Palm warbler	S	M		M
+ Yellow warbler	S	S		S
Tennessee warbler	S	M		M
Orange-crowned warbler	M	M		M
Wilson's warbler	M	M		M
Golden-winged warbler	S	S		S
Nashville warbler	S	M		M
Connecticut warbler	S	M		M
Mourning warbler	S	M		S/M
+ C. yellowthroat	S	S		S
+ N. waterthrush	S	M		M
Louisiana waterthrush		S		S
+ Red-winged blackbird	S	P		P/S
+ Yellow-headed blackbird	S	S	S local	S
Rusty blackbird	M	W		W
C. grackle	S	P		P
Starling	P	P		P
N. oriole	S	S		S
Common redpoll	W	W	W	W
Hoary redpoll	W	W	W	W
Purple finch	S/P	W		W
Am. goldfinch	S	P		P
Rose-breasted grosbeak	S	S	S	S
Indigo bunting	S	S	S	S
White-throated sparrow	S	M	M	W
White-crowned sparrow	M	M		M
+ Swamp sparrow	S	S	S	P
+ Song sparrow	S	P	S	P
+ Lincoln's sparrow	S	M		M
Savannah sparrow	S	S	S	S
Henslow's sparrow		S		S
Sharp-tailed sparrow	S			
+ LeConte's sparrow	S	M		M

(Table 1 continued next page)

(Table 1 continued)

Mammals	North	South	Prairie	Lower Michigan
Opossum		X		X
Masked shrew		X	X	X
Arctic shrew	X			
+ N. water shrew	X			
Pygmy shrew	X	X	X	
Least shrew		X		
Shortail shrew	X	X	X	X
BATS-Aerial and/or tree roosters				
Little brown myotis	X	X	X	X
Keen myotis	X	X	X	X
Indiana		X		X
Silver-haired bat	X	X	X	X
E. pipistrel		X		
Big brown bat	X	X	X	X
Red bat	X	X	X	X
Hoary bat	X	X	X	X
Black bear	X			
Raccoon	X	X	X	X
Fisher	X			
Short-tailed weasel	X	X	X	
Long-tailed weasel	X	X	X	
Least weasel	X	X	X	X
+ Mink	X	X	X	X
+ River otter	X	X	X	X
Spotted skunk		X	X	
Striped skunk	X	X	X	X
Red fox	X	X	X	X
Gray fox	X	X	X	X
Coyote	X	X	X	X
Gray wolf	X			
Lynx	X			
Bobcat	X			
Franklin's gr. squirrel		X	X	
+ Beaver	X	X	X	X
Deer mouse	X	X	X	X
White-footed mouse		X	X	X
S. bog lemming	X	X	X	X
Boreal redback vole	X			
Meadow vole	X	X	X	X
+ Muskrat	X	X	X	X

(Table 1 continued next page)

(Table 1 continued)

Mammals	North	South	Prairie	Lower Michigan
Meadow jumping mouse	X	X	X	X
Woodland mouse	X			
Snowshoe hare	X			
Cottontail		X	X	X
White-tailed deer	X	X	X	X
+ Moose	X			

Herpts	North	South	Prairie	Lower Michigan
TURTLES				
+ Snapping turtle	X	X	X	X
Wood turtle	X			
+ Spotted t.				
+ Stinkpot		X		X
+ False map t.		X		
+ W. painted t.	X	X	X	
+ Midland painted t.				X
+ Blandings turtle		X		X
SNAKES				
N. red-bellied snake	X	X	X	X
+ Texas brown s.		X		
+ Midland brown s.				X
+ Northern brown s.				X
+ N. water s.				X
+ Kirtland's water s.				X
+ Queen snake				X
+ W. Plains garter s.		X	X	
+ E. Plains garter s.		X		
+ Red-sided garter s.			X	
+ E. garter s.	X	X		
+ E. ribbon s.				X
+ W. ribbon s.		X		X
Blue racer		X		
W. smooth green s.		X	X	X
E. smooth green s.	X			
W. fox snake	(U.P.	X		X
E. fox snake				
+ Black rat snake				X
+ E. massasauga		X		X
				X
+ **SALAMANDERS**				
Mudpuppy	X	X	X	X
Blue-spotted sal.	X	X		
Jefferson sal.		X		X
Spotted sal.		X		X
E. tiger sal.		X		
Cent. newt	X	X		X
Red-spotted newt				X
Four-toed sal.	X	X		X

(Table 1 continued next page)

(Table 1 continued)

Herpts	North	South	Prairie	Lower Michigan
+ **TOADS & FROGS**				
Great Plains toad			X	
American toad	X	X	X	X
Dakota toad			X	
Blanchard's cricket frog		X		X
N. spring peeper	X	X		X
E. gray treefrog	X	X	X	X
Boreal chorus frog	X		X	
W. chorus frog		X		X
Bullfrog	(Wis&E U.P.)			X
Mink frog	X			
Green frog	X	X		X
N. leopard frog	X	X	X	X
Pickerel frog		(Wis.&E U.P.)		X
Wood frog	X	X		X

+ = Wetlands
S = Summer
W = Winter
P = Permanent
M = Migrant

Impoundments are especially beneficial to water birds. After the flooding of a freshwater impoundment in Ontario, Boyer and Devitt (1961) noted a "substantial increase in species of water birds already common to the region and an extension of ranges of others." He also demonstrated its importance as a duck production center and as a resting place for migrating waterfowl.

Mammals

Of 67 mammalian species in the Lake States, 6 could be classified as having wetland habitats (mink, river otter, muskrat, beaver, northern watershrew, and moose) and about 40 others as being associated with or attracted to wetland edges. We recorded 38 mammals associated with impoundments in the Chippewa.

Herpts

Thirty-four reptile and 22 amphibian species occur in the Lake States. Of these 56 species, 28 prefer wetland habitats and another 12 can be found in edge habitats or in wet areas for breeding only. In the table, subspecies of some herpts are listed due to distinctive range or habitat characteristics. Lower Michigan has 10 species or subspecies not found in the other Lake States region.

A total of 412 vertebrate species may be found in the region, of which 264 can be associated with wetlands or wetland edges. The vertebrate list for the wetlands of the Chippewa National Forest, based on our study (Probst *et al.* 1983) plus those of Mathisen *et al.* (1974) and Kirby (1975), was 157 birds, 44 mammals and 14 reptiles and amphibians for a total of 215 out of 308 species listed on the Chippewa National Forest.

HABITAT FACTORS

Water

Water provides a source of food, cover, and drinking water for a variety of wildlife. In his study of beaver flowages, Kirby (1975) estimated that 4 mammals, 22 birds, and 6 herpts, would not have been present without the occurrence of open water.

According to Karr (1968), the addition of open water areas results in an increase in the heterogeneity of the habitat with a corresponding rise in the distribution and abundance of birds. Reese and Hair (1976) also noted an increase in avian use by species not normally associated with wetland habitat, on an area recently flooded by a beaver dam.

The principal birds of open water in the region are waterflowl, with 22 species of ducks, swans and geese; 5 grebes; loon and coot. Piscivorous birds such as king-

fishers, cormorants, terns, and herons are also benefited. Loons and diving ducks need expanses of open water for takeoff. Another group of birds uses the open space over water for aerial foraging, either hawking after insects or sighting prey in or around the water. These include nighthawks, swallows, terns, ospreys, and bald eagles. Common snipe often perform their aerial courtship displays over open water.

Bats also utilize the aerial space over the impoundments, especially in forested areas. Other mammalian species such as the muskrat, river otter, and beaver are totally dependent on the aquatic habitat. Mink, reacoon, and moose rely heavily on water areas for food resources.

The presence of water is critical to many reptiles of the Lake States and to all amphibians for some part of their life cycles. All amphibians breed in water and spend either their larval or adult form in aquatic environments. Many snakes use aquatic edges for the abundance of prey found there, and most turtles in the Lake States are aquatic.

Food

Open water provides a direct source of food for many wildlife species, in the form of aquatic vegetation, invertebrates, and fish. With their high net productivity, water impoundments support the entire aquatic food chain. This is especially true in the younger vegetative stages which can be maintained in impoundments through water level manipulation (Probst *et al.* 1983, Harris and Marshall 1963, Kadlec 1962).

Plant Food

Primary production in impoundments is heavily based on aquatic plants. They provide either a direct or indirect source of food for herbivores or primary consumers. As a direct source they produce seeds--an important food source for many birds and small mammals--in greater quantities than other habitats. In a study of wetlands in southeastern Wisconsin, Wheeler and March (1979) found seeds to be very numerous in bottom samples from all types of wetlands and stressed their "important role in wetland use and potential waterfowl value". Seed production by aquatic vegetation is stimulated by slowly declining water levels (Keith 1961) which can be part of an impoundment management plan. Some important seed-producing plants include pondweeds (*Potamogeton* spp.), smartweeds (*Polygonum* spp.), wild rice (*Zizania aquatica*), arrowheads (*Sagittaria* spp.), spikerushes (*Eleocharis* spp.), bulrushes (*Scirpus* spp.) and sedges (*Carex* spp.). Evans and Kerbs (1977) call the widespread sago pondweed (*Pontamogeton pectinatus*) the "most important single waterfowl food plant". A species like wild rice not only provides a good food source but also good cover.

Although seeds are important for many ducks and other birds, vegetative plant parts also provide food. Wigeons and gadwalls make less use of seeds and fruits (Keith 1961) and feed more upon the leaves and stems of aquatic plants. Canvasbacks and other divers also feed on vegetative parts as do some turtles, beaver, muskrat, white-tailed deer, and moose. Minnows and tadpoles eat algae and other vegetation.

Animal Food

Aquatic vegetation provides an indirect food source by serving as a "culture medium" (Stoudt 1944) for invertebrates, which are especially important for waterfowl broods. Moyle (1961) relates the production of invertebrates both to the type and volume of aquatic vegetation present. Plants with finely dissected leaves or many branched stems are usually most productive as a base for invertebrates. For example, coontail (*Ceratophyllum demersum*) is not a good direct food source but harbors quantities of aquatic insects (Evans and Kerbs 1977). Duckweed (*Lemna* spp.) and Bladderwort (*Utricularia* spp.) also support large quantities of invertebrates. Whitman (1976) states that duckweed harbors "significantly larger numbers of invertebrate taxa than any other" aquatic plant. Invertebrate populations are greater in new impoundments and much reduced in older impoundments that are not managed (Kaminski and Prince 1981). Some abundant and widespread plants like cattail provide good cover but are relatively poor for producing invertebrates.

Many researchers have noted the reliance of waterfowl on animal foods during egg-laying periods. Wheeler and March (1979) give figures of 58.7 percent animal food for pre-laying blue-winged teal hens and 92.8 percent for laying hens. Ducklings also consume significant quantities of invertebrates. Bird species can differ as to which insect life stages they utilize. Although duck broods consume aquatic and larval forms, swallows and other aerial foragers eat the adult flying forms.

Food Chain

Carnivores and herbivores are attracted to this highly productive food chain provided by aquatic vegetation and invertebrates. Impoundment herbivores include muskrat and beaver, both of which feed on emergent and aquatic vegetation. Deer and moose are attracted to these areas to feed on the aquatics and wetland shrubs. Small mammals make use of the abundant seed production along impoundment edges. Invertebrates are food sources for snakes, turtles,

frogs, shorebirds, rails, some waterfowl, and wetland passerines such as marsh wrens and blackbirds. Amphibians, snakes, and the larger invertebrates are in turn consumed by herons, egrets, raccoons, and mustelids. Many wildlife species are attracted to impoundment edges for food and water. Skunks and raccoons are particularly fond of these areas and also pose a serious threat to waterfowl nesting. The interspersion of edges created by new impoundments is also beneficial to black bears, fox, fisher, and bobcats. As noted above, many waterfowl species depend on the vegetation as do some turtles, tadpoles, minnows, and fish such as bullheads and carp. The fish in turn provide an abundant supply of food for piscivores. Mergansers, loons, cormorants, kingfishers, terns, ospreys, bald eagles, and herons all benefit from this resource. Among mammals, otter and mink prey not only on fish but also on crustaceans and amphibians.

Food Availability

Although newly flooded impoundments possess abundant plant and invertebrate food resources, they often are not readily available to the feeding animal. Water levels influence both the type of vegetation that is present in an impoundment of its availability. When impoundments are too deep, dabbling ducks have difficulty reaching the bottom. For example, as the water depth increased, Wheeler and March (1979) noted that diets of dabbling ducks shifted from seeds to invertebrates. He also observed that mallards and blue-winged teal utilized seeds and insects in proportion to their abundance and availability. Low water levels benefit shorebirds by exposing mudflats for foraging and are attractive to waders by concentrating prey species in shallow pools. Dense stands of emergents may have abundant invertebrates, but access and movement are restricted. A dense edge of shrubs will also restrict wildlife access.

It's obvious there will be regional and seasonal differences in the abundance and availability of various food sources. Insects emerge at different times over the spring and summer months. There also may be conflicting habitat requirements among species. For example, a dense edge of willows will provide good forage for deer and moose but it also impedes access to the impoundment for other wildlife. Cattails provide food and shelter for muskrats but dense stands limit use by waterfowl.

Fluctuating Water Levels

As mentioned previously, several studies have shown that during the first year after flooding there is an increase in the density and diversity of wildlife followed by a decline after a few years. But fluctuating water levels can benefit wildlife by retarding hydric succession and maintaining vegetation in younger stages of higher net productivity. The final links in the food chain, the decomposers, are aided by drawdowns in impoundments which expose the organic material on the bottoms. As Kadlec (1962) and other researchers have noted, many productive waterfowl areas are drawn down naturally during droughts. This is successfully imitated in artificial water impoundments where the level can be manipulated.

In direct response to vegetation change, invertebrate food sources also react favorably to fluctuating water levels. Another important aspect of fluctuating water levels is the exposure of mudflats which attract shorebirds. Other drawdown effects are covered in more detail elsewhere in the workshop proceedings.

Habitat Complexity

The increase in interspersion due to water level fluctuation results in an increase in habitat complexity. MacArthur (1964) and Rothe (1976) have related increases in avian diversity to patchiness of habitat. Other studies (MacArthur and MacArthur 1961, Willson 1974, Probst 1979) have linked avian diversity to the vertical complexity of foliage. Karr's (1968) research suggests the addition of open water adds a major structural factor to the habitat which leads to an increase in the abundance and diversity of wildlife. In a study on beaver flowages, Reese and Hair (1976) found that open water increased the potential for production of food sources which in turn attracted non-wetland species. Bird, mammal, reptile, and amphibian species are attracted to the interspersed impoundment habitat.

The initial flooding and subsequent water level manipulation in an impoundment increase the amount of edge and the degree of interspersion of habitat types. This interspersion of open water, emergents, shrubs, upland openings, and timber results in greater numbers and kinds of wildlife. Leopold (1933) relates edge to animal numbers. Diversity and density of species is a function of the number of kinds of edge and density is also a function of the total length of edge. Weller and Frederickson (1973) found the peak of avian production to occur when the emergent plant to water ratio was about 50:50. Kaminski and Prince (1981) found the same ratio to be optimum for dabbling duck breeding pair densities and species density. In studies of a flooded timber area, Cowardin (1969) found the highest waterfowl use near edges where dead timber was interspersed with emergents, and Harris (1957) found that interspersion increased nesting opportunities for ducks.

SUGGESTIONS FOR HABITAT MANAGEMENT

Once the need for an impoundment is established, the land manager should select a site that maximizes the interspersion of habitat types after flooding for the greatest diversity of wildlife species. These types should include open water, emergent vegetation, wetland shrubs, flooded dead timber, and adjacent edges of upland openings, shrubs, and live timber. Depending on the location, some of these types may not be present or the goal may be to manage for a single species or group of species, such as the osprey, muskrat, or dabbling ducks. Most management to date has been for game and some furbearing species. Tradeoffs may have to be made when deciding management objectives.

Open Water

As noted before, open water areas add greatly to the habitat heterogeneity and diversity of wildlife. Impoundments with expanses of open water are attractive to osprey, kingfishers, terns, muskrats, beaver, and most waterfowl, especially common loons, ring-necked ducks, common goldeneyes, and mergansers. Open water areas with submerged and floating-leaved vegetation provide food for beaver, moose, and other animals. From our study (Probst *et al.* 1983) 2 ha of open water appears to be minimum for attracting waterfowl to this habitat. Most waterfowl prefer small areas for raising broods. Impoundments usually provide this. Depths less than 18 inches are ideal for dabbling ducks (Linde 1969). Larger open water expanses are needed for the flightless period (Gilmer 1977), thus impoundments located adjacent to larger bodies of water should be more attractive to waterfowl. The same could hold true for the migration periods. In the smaller, shallower impoundments the surface water warms faster and provides food for early migrants (Swanson *et al.* 1974.

Vegetation replaces open water areas when water levels are not managed. Bogs of the northern Lake States are prime examples of this problem.

Emergents

Dense stands of emergent vegetation provide thick cover, an abundant invertebrate food supply and poor-to-good vegetative food supplies. Birds such as the least and American bitterns, sora and Virginia rails, long-billed marsh wren, and yellow-headed blackbirds utilize these areas exclusively. While some waterfowl like the redhead and ruddy duck use them for nesting. But only when they are interspersed with a variety of other habitat types do they provide the optimum benefit for the greatest diversity of wildlife.

Emergent cover is vital for waterfowl broods, but if too dense, it impedes movement. Interspersion with patches of open water provides access to the abundant insects and facilitates escape from predators. Once emergent stands are opened up, other wildlife is attracted. Terns, ducks, grebes, coots, and gallinules will build nests on mats of dead vegetation and forage in these openings. Muskrats will create openings and their houses provide nesting and loafing platforms.

Monotypic stands of emergents, especially cattails, are detrimental. Cattails provide good cover but low food quality for most wildlife species except muskrats. In contrast to cattails, bulrushes and wild rice provide both excellent food and cover.

White-tailed deer often feed on emergents in shallow waters. Other wildlife not associated with wetlands utilize emergent vegetation in winter months. Pheasants, prairie chickens, and cottontail rabbits may use these areas for winter cover, especially in the agricultural and prairie regions where suitable habitat is scarce. On a SE Wisconsin study area, two-thirds of all successful pheasant clutches were located in wetland cover (Gates 1970).

Wetland Shrubs

Flooded shrubs provide nesting and resting cover for a number of wildlife species but will die if flooding is too deep. Willows or alders can quickly invade the shoreline after a drawdown and in 3 to 5 years will close in the edge (Harris 1957) if there are no subsequent controls. Shrubs can supply browse for deer and moose at this stage but are generally detrimental. Once again, interspersion with other types is more beneficial. When interspersed with emergents, shrubs are especially good for dabbling ducks and broods. Wood ducks are commonly found in them and shrub swamps are favored nesting areas of black ducks.

Smaller passerine birds like the eastern kingbird and alder flycatcher may also nest in wetland shrubs. They also forage from them as do the swamp sparrow, song sparrow, common yellowthroat, red-winged blackbird, and yellow warbler. Migrant warblers make much use of wetland shrubs, especially in spring. Ruffed grouse may use alder swamps for brood cover and feeding (Golet 1972). Along with deer and moose, beaver use them as food. In non-forested regions, wetland shrubs provide valuable winter cover for pheasants, cottontails, (Golet 1972) and other wildlife. In northern regions snowshow hare will use shrub swamps as winter cover.

Flooded Dead Timber

Another major habitat component of impoundments is flooded dead timber. It is attractive to cavity nesters such as wood ducks, goldeneyes, mergansers, and tree swallows, and may be used by colonial nesting herons, cormorants, and osprey. The timber provides foraging perches for kingfishers, raptors, shrikes, and flycatchers and a foraging substrate for woodpeckers and nuthatches. Kadlec (1962) noted that flooded areas of dense timber can provide a refuge for waterfowl in the hunting season.

Dense stands with numerous fallen trees provide roosting and loafing sites for many waterfowl, turtles, and other wildlife. These stands reduce wind and wave action. As a result, dense masses of duckweed often form, which in turn provide an ample food source. When drawn down, flooded timber areas are rapidly invaded by emergents and the resulting mix of vegetation leads to greater wildlife use (Cowardin 1969).

Our study (Probst *et al.* 1983) found 35 bird species in flooded timber areas, 6 of which were not recorded outside this habitat type, including the green heron, red-headed woodpecker, tree swallow, and shrikes.

Nesting Structures

Providing nest structures (nest boxes, platforms, or islands) can be part of impoundment management plans. Nest boxes can be put up for wood ducks, goldeneyes, and mergansers but may also be utilized for nesting or cover by screech owls, kestrels, tree swallows, starlings, flickers, flying squirrels, raccoons, deer mice, and others. The placement of boxes is important because they can be more vulnerable to predation than natural cavities (Bellrose *et al.* 1964). In one impoundment, we observed a mink systematically entering boxes placed over water on poles. Conical shields placed around the poles could have prevented this predation. Other animals that cause problems include raccoons, fox squirrels, starlings, and some snakes. According to Bellrose (1976) risk of predation is increased when unshielded boxes are grouped closer than 1 per 10 acres. If boxes are shielded, groups of 2-4 per acre have the highest use.

Platforms are useful to some wildlife, especially Canada geese (Rienecker 1971). Nest baskets have been used by the adaptable mallard. Osprey and cormorants may use suitably located platforms. Meier (1981) reported greater production for cormorants on artificial platforms than natural nest sites. Great blue herons also used the platforms.

Islands, natural or man-made, are favored nesting and loafing spots for waterfowl and are used by other birds and turtles. According to Giroux (1981) artificial islands may cost more than nest boxes or platforms but they require less maintenance. Also, more ducklings and goslings are hatched per unit areas on islands and they are used by a greater diversity of species.

Loons and ring-necked ducks prefer islands for nesting and Canada geese, mallards, and other waterfowl also use them when available. In large impoundments, islands could possibly be used by colonial nesters such as the common tern or white pelican. McIntyre and Mathisen (1977) reported that artificial islands were used as readily as natural islands for nest sites by common loons. Sedge mats 40-60 cm thick and 1-6 m^2, were cut with a hay saw and anchored in open water 1-2 m deep and 3 to several hundred m from the shore. Ring-necked ducks especially favor the sedge-mat islands. Linde (1969) describes another method of island construction for areas without sedge mats. In winter, either brushpiles covered with hay or piles of earth are placed on top of the ice. These are particularly good for Canada geese and mallards, but last only 1-4 years depending on the weather. Another technique is to bulldoze a "push-up" of earth after a drawdown. To reduce erosion of islands, managers should consider distance from shore, water depth, and placement.

Other artificial structures for impoundments include placing loafing logs for ducks and turtles and erecting perches for osprey and other raptors or piscivores.

Drawdowns

Water level manipulation techniques are covered more thoroughly elsewhere in this workshop proceedings. In general, drawdowns permit the release of nutrients trapped in bottom soils, prevent drowning of shrubs, and stimulate the growth of emergents. All this increases interspersion of cover and water, increases food, and results in a greater abundance and diversity of wildlife species.

More research is needed on the timing and duration of drawdowns, and whether they should be partial or complete. These considerations impact groups of wildlife differently. The habitat and food requirements of wildlife are diverse so land managers must define their wildlife objectives. Waterfowl habitat is a primary concern in many areas, but managers can also enhance other wildlife in conjunction with waterfowl or as an alternative goal.

A gradual drawdown that continually exposes new mudflats is very beneficial to shorebirds (Rundle and Fredrickson 1981). These mudflats are especially important in northern forested areas and during peak shorebird migration in August. Fewer duck broods were noticed by Keith (1961) where mud shorelines existed, thus any drawdown during the brood season

may be detrimental. Subsequent reflooding after shorebird passage could benefit migrating waterfowl and retain more for the hunting season.

Drawdowns can be used to remove pest species such as carp, snapping turtles, and muskrats if they are adversely affecting vegetation and waterfowl. Also during drawdowns, islands can be constructed and the basin seeded for waterfowl food or cleared of debris if necessary. Wading birds are attracted to drawdowns where amphibians and fish are forced into shallower pools of water. The same holds true for raccoons and other carnivores. Overwinter drawdowns could control muskrats or carp but at the same time would reduce the number of amphibians and turtles that burrow into the bottom mud. Invertebrate populations may be adversely affected by drawdowns, depending on their extent and duration (Linde 1969, Swanson 1977).

Create Openings

Managers can create openings in the impoundment proper by manipulating water levels. Upland clearings around the impoundments edge should also be considered for wildlife nesting, food, and cover needs. Dams or dikes built to impound water furnish suitable habitat for some species such as killdeer, spotted sandpipers, meadow voles, jumping mice, and ground squirrels. Waterfowl may use them for loafing sites but nests located there would be too vulnerable to predation. The smaller the area of upland nesting the greater the vulnerability to predation (Moyle 1964). Low and tall grasses mixed with herbs would be beneficial. Some dabbling ducks will nest up to 500 yards from water (Moyle 1961). Pheasants will use nesting cover around impoundments in agricultural areas (Gates 1970). Greater wildlife diversity is achieved if there is a mixture of forest and upland openings around the impoundment.

Fish Management and Crop Planting

Fish management and crop planting are additional management techniques to consider. Minnows are important links in the food chain and should be considered when planning drawdowns. Managing for fisheries will be covered in another workshop paper.

Wildlife food crops can be planted to attract and hold waterfowl populations during the fall migration. Upland crop planting can provide food and cover for other wildlife as well. Mudflats can be exposed with summer drawdowns, seeded, and reflooded in fall (Harris 1957). In SE Wisconsin, Linde (1969) found buckwheat and Japanese millet can be artificially seeded with success. Wild rice proved to be the most successful crop in Emerson's (1961) study. Impoundment basins can also be tilled for planting during drawdowns.

SUMMARY

Table 2 summarizes the benefits described in the main text. It covers habitat needs and management strategies for certain species or groups of species.

Land managers should first define their wildlife goals. Endangered, threatened, or sensitive species may warrant special consideration. This would still benefit many other species but the optimum benefit for the greatest number and diversity of species will result from the maximum interspersion of open water, emergents, wetland shrubs, and flooded timber. Reptile and amphibian numbers are generally increased by practices that benefit other wildlife, but complete drawdowns could have a drastic effect on local populations.

In addition to the traditional values held for waterfowl and other game species, many nongame species are esthetically valued by nonconsumptive users. Impoundments can attract wildlife and provide hunters, trappers, fishermen, birders, nature photographers, and nature study groups with recreation.

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Table 2.-- *Habitat improvement for vertebrate species and species groups*

Habitat improvement	Waterfowl	Shorebirds	Waders & waterbirds	Piscivores	Raptors	Insectivores	Others
Open water	loon mergansers ring-necked d. mallard	phalarope	herons egrets cormorants coots	kingfisher gulls terns	osprey bald eagle		otter muskrat beaver turtles
Emergents	b.w. teal redhead ruddy duck grebes		sora Virginia rail bitterns c. gallinule	terns (nests)	harrier	marsh wrens blackbirds swamp sparrow	muskrats pheasants (Wntr cover) beaver
Wetland shrubs	wood duck black duck		green heron			e. kingbird alder flycatcher c. yellowthroat yellow warbler song sparrow	beaver moose deer
Flooded dead timber			green heron great blue h. cormorant	kingfisher	osprey b. eagle kestrel	tree swallow flycatchers starlings woodpeckers	bats
Mudflats		spot, sandpi. killdeer yellowlegs snipe	herons			grackles	raccoon mink
Upland openings	nesting ducks	nesting sp. killdeer spot, sandpip.	sandhill crane		harrier s.e. owl	sparrows flicker	gr. squir. fox
Forest edge mgmt	wood ducks				red-sh. hawk owls	forest passerines	squirrels tree frogs
Crops	geese	godwits (cover)	sandhill crane		harrier	red-winged blackbird	pheasants
Perches			cormorants	kingfisher	osprey eagle		
Boxes	wood duck c. goldeneye mergansers				kestrel	tree swallow flicker crested flyc. screech owl	raccoon squirrels snakes
Platforms	geese		cormorants		osprey		
Sedge islands	loon ring-necked d. grebes		rails bitterns	terns			

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BEAVER IN WATER IMPOUNDMENTS: UNDERSTANDING A PROBLEM OF WATER-LEVEL MANAGEMENT

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The North American Beaver (*Castor canadensis* Kuhl, 1820) is one of two species belonging to the family Castoridae. It now occurs throughout North America except in peninsular Florida, deserts of the Southwest, and in the arctic tundra (Jenkins and Busher 1979). However, this distribution was broken in recent history. The quest for beaver pelts was a strong stimulus to exploration of this continent by Europeans. The result of this unregulated harvest was the extirpation of beaver throughout most of the contiguous United States by the early 1800's. There was a transition period during the late 1800's and early 1900's when numerous States prohibited the taking of beaver. The early 1900's was also a period during which numerous States began reintroducing and relocating beaver. In the Upper Midwest, this transition period also coincided with the pine logging era that subsequently resulted in abundant aspen forests favorable to beaver. In Minnesota the beaver had returned in sufficient numbers by 1940 to warrant the establishment of a regulated harvest (Longley and Moyle 1963).

The return of abundant beaver populations also brought problems, the same problems that we experience today (Peterson 1979, Woodward *et al.* 1976). They have a proclivity for building dams in ditches, along roadsides, in culverts, under small bridges, etc. Dams in these locations cause flooding, much to the dismay of highway departments, lake property owners, foresters and farmers. They frequently cut down ornamental or valued trees along lake or stream property. Lastly, and this addresses the subject of this symposium, they find artificial impoundments created for waterfowl to be quite suitable habitat. However, they instinctively respond to escaping water, whether from an impoundment full of water, or from one that is being rejuvenated through drainage. The result is plugged water control structures and conflicts with management plans. The intent of this paper is to explore these problems.

First I will lay a basis for understanding the problem by reviewing beaver natural history. I will selectively draw upon the literature and impressions I obtained from our beaver research. Next, I will reveiw what is known about their habitat requirements. Then, I will discuss the problems beaver cause in impoundments and why these problems occur. Finally, I will offer some potential solutions.

NATURAL HISTORY

Social Organization

The social organization of beaver is uncommon among mammals. They are monogamous, which means that they have a single mate who is usually retained for life. If their mate dies, they obtain a new mate from among the population of dispersing 2-year olds, unmated adults, or from among members of their family. Another trait of beaver that is uncommon in all but the larger mammals is their long parental care period. This period of development and association with their parents and other kin typically lasts 2 years.

The term "colony" is well entrenched in the literature on beaver. Actually this is a misnomer, for a beaver colony is more accurately a family of related individuals. The family can include a pair of adults and their offspring from the pervious 2 years. However, this "typical" family is only one of many possible combinations. Fur trapping, predation, and other causes of death distort family composition. Other factors such as habitat quality also affect family composition; thus reports of family composition vary greatly. Reports of the frequency of "typical" families (those with adults, yearlings, and kits) range from 19 percent (Bradt 1938) to 64 percent (Hodgdon 1978).

Family size and age class composition also vary with the above factors. The average family size for 22 studies listed by Hodgdon (1978) is 4.9 with a range of from 2.7 to 7.8. Conditions ranged from good to poor habitat and from exploited to unexploited populations. Hodgdon (1978) reported a population age class structure of 28 percent adults, 3 percent 2-year olds, 32 percent yearlings, and 37 percent kits, which is similar to reports of others (Payne 1982, Shelton 1966). How-

ever, age class structure varies widely. For example, the percentage of adults reported in 22 studies listed by Hodgdon (1978) ranges from 15 to 61 percent.

Reproduction

In northern regions, beaver breed once each winter from late January to early March with peak breeding in mid-February (Bergerud and Miller 1977, Hodgdon and Hunt 1966). Only the adult pair is reproductively active within the family unit. The gestation period is about 107 days (Wilsson 1971) and the young are born in May and June (Bergerud and Miller 1977, Hodgdon and Hunt 1966). Usually there are 3 to 4 kits in a litter although Novak (1972) reported that one female had 12 fetuses. The average litter size for 26 studies listed by Hodgdon (1978) was about 3.6. Litter size has been reported to vary with age, weight of female, quantity and quality of available food, and severity of winter (Boyce 1974, Henry and Bookhout 1969, Hodgdon and Hunt 1966, Pearson 1960, Rutherford 1964, and Yeager and Rutherford 1957).

Ontogeny and Dispersal

At birth, the kits weigh about 1 pound, are fully furred, their eyes are open, and their incisors have erupted. Within about 2 weeks (Wilsson 1971), they become interested in sampling herbaceous vegetation, principally the foliage of trees and shrubs brought into the lodge by the adults. Their milk diet is increasingly supplemented by vegetation brought into the lodge or cached on the lodge exterior. At the age of about 2 months, near the end of July or early August, they are weaned and appear increasingly outside the lodge to forage on their own nearby. By fall, they range almost as far from the lodge as older members of the family; however, they seldom venture on land or participate in a substantial way in lodge maintenance or constructing a winter food cache (Hodgdon 1978). By the time ice-up occurs, they usually weigh about 10 to 16 pounds.

During their second year with the family as yearlings, they participate more in construction, but not as much as adults do. They generally stay with the family until nearly two. They disperse as the ice leaves in the spring. Contrary to popular notion, there is considerable evidence that they are not driven off by the adults (Hodgdon 1978).

Dispersing beaver travel faster through occupied habitat than through unoccupied habitat (Hodgdon 1978). While traveling through the territories of resident beaver, they seldom stop. Residents show little interest in transients, even in one instance, when a transient passed within 3 m of a resident. After leaving an occupied territory, they reduce their rate of trave and resume normal activities.

Dispersal distances vary considerably. During dispersal, they move up to about 1.4 miles per day (Hodgdon 1978). Most dispersal is by water although the sometimes travel over land. Dispersing beaver hav been known to travel up to 50 miles from the nata colony, but the average is closer to 5 to 6 miles (Hibbard 1958, Hodgdon and Hunt 1966, Hodgdon 1978) During the dispersal period, they attempt to locate mate, either an unpaired adult, another unrelated 2 year old, or in some cases a sibling. If successful, the form a pair bond, mate the following winter, and produce their first litter at age 3.

Mortality

The cause and magnitude of mortality in beave populations depends on local circumstances. Fur trapping, diseases, and predation can result in consider able mortality. In their absence, mortality is generall low, especially within the kit and yearling age classe (Hodgdon 1978). It is generally assumed that there i substantial mortality in the 2-year-old age class be cause of losses during dispersal.

Food Habits

The food habits of beaver suggest that they ar "choosy generalists" (Jenkins and Busher 1979). Th is, although they feed upon a wide variety of veget tion, they definitely prefer far fewer species. Beav are best known for cutting and eating the bark of tree but their diet is far more varied. Woody bark form the bulk of their diet, especially during the leafle seasons. If preferred tree species are not readily avai able, they eat the bark of shrubs instead. Howeve even during this period, other food sources are use when available. For example, they may feed on aquat plants that stay green all winter or on the root systen of aquatics such as the tubers of water lilies.

In the spring, the diet of beaver shifts from primari woody bark to the developing herbaceous vegetatio At this time, they venture up to 10 m from shore feed upon grasses, carex, and forbs, or the foliage trees and shrubs adjacent to the water. As emerge and aquatic macrophyte vegetation develop, they a eaten. Thus herbs, foliage, emergents, and aquati form the bulk of their diet during the summer mont (Svendsen 1980b). If aspen is available near the sho their summer diet may also include aspen bark a leaves. Toward fall, when the foliage of trees, shrub and herbaceous vegetation gets scarce, beavers tu again primarily to woody bark and aquatics.

Habitat quality is partly dependent on the availa-ility of aspen and to a lesser extent aquatics. Shelton 1966) showed that beaver subsisting on aspen or quatic macrophytes grew the best. Huey (1956) re-orted that litter sizes were larger for beaver subsisting n aspen than on willow or cottonwood. Thus aspen s preferred and beneficial to both their growth and roductivity; the less there is the more beaver must eek out other food.

Territoriality

Beaver are territorial and communicate their pres-nce within an area by constructing scent mounds. 'hese are small mounds of mud, grass, and other de-ris located at the water's edge. They are placed most requently at the perimeter of their territory and near ctivity centers. Beaver urinate on these mounds and n the process of urinating, castoreum from the castor lands is also deposited. Hodgdon (1978) reported that ll family members older than 1 year participate in cent mounding, but adults are most active. While bea-er are dispersing, they do not build scent mounds ntil they begin to settle in an area. At this time they ctively create mounds, which advertises their pres-nce in a territory.

Scent mounding behavior among residents is strong-st in spring which corresponds with the dispersal per-od (Hodgdon 1978, Svendsen 1980a). Although scent nounds do not function as a "scent fence" (Svendsen 980a), (transient beaver will pass through occupied erritories), it does advertise the presence of residents o other beaver. Towards summer, this behavior and heir interest in scent mounds wane. The exception to his penological pattern is when a family moves to a ew site. During the initial period of establishment at he new site, scent mounding is intense, then wanes.

The home range of beaver varies considerably and artly depends on the characteristics of the body of ater they are located upon. Lakes less than 80 to 100 cres in size with a low shore-to-area ratio usually ontain only one family. On very large lakes, where ave action can be substantial, beaver lodges usually re found in sheltered bays, although their territories ay include the nearby more exposed shorelines. On treams, their territories include not only the im-ounded water about the lodge, but also the stream ections above and below the dam perhaps extending s far as ¼ mile.

Beaver may change territories over the years de-ending on their quality. This is particularly true of erritories that have marginal food resources. On lakes here food is scarce they use a different lodge each inter. On streams, they move to a different portion of the stream. In this manner they increase their efficiency and safety by not having to travel farther to obtain the food that they need from a declining resource base. This also results in a sort of rest-rotation of their food resources. In many cases, these moves are primarily a shift of activity centers within the same territory. However, they may continue to use the old lodges or impoundments, only less frequently. Where food is abundant, it is less likely that they will shift their activity center within the territory or move to a different location. In these situations, they may use the same lodge year after year.

Construction Behavior

There is a definite sequence and seasonality to their construction activities. If they are going to move, they usually do so either before the kits are born or more likely after the kits become somewhat independent. This means that they are likely to move in April to May or in August to September. Beaver without young are not restricted and therefore may more any time between April and September, but are more likely to establish themselves at new sites between June and August (Hodgdon 1978).

The sequence of construction activity depends on the availability of existing structures and the characteristics of the site. If a dam, a lodge, or both, already exists, they will generally use these structures after refurbishing them. Or, they may build other dams or lodges. If no structures exist, they begin by building a dam. During this period, they are usually either commuting from another lodge or living in a bank den that was recently constructed or already existed.

They begin the dam by placing branches at the chosen site and adding mud and other debris obtained from the bottom near the dam. Once the height of the dam is near the intended level (which usually creates a pond about 1.5 m deep), they begin construction of the lodge. A lodge may begin with several lodge starts, each start being a small pile of sticks on some prominence such as a mound of dirt, rock, or tree base somewhat above water level. They prefer lodge sites that are surrounded by water, but sometimes build along the edge of the impoundment, either within emergent vegetation or on the shore. Eventually, one lodge start is chosen, more sticks are added, a tunnel is constructed from below water, and a chamber is hollowed out under the pile of sticks. After a substantial pile of sticks accumulates, they add bottom mud to the lodge. Most mud is placed on the sides of the lodge with very little at the top. This results in a pathway for ventilation between the chamber and the outside air. This sequence of construction is important because the floor of the lodge is uniformly about 1 dm

above water, which doesn't leave much room for error. Because these construction behaviors are separated in time, there is less need for decision processes than would be required if they constructed both the dam and lodge simultaneously.

If one or several lodges already exist and they are not going to change location or construct a new lodge, they begin to maintain an existing lodge during late August or September. Again, they may start maintaining several lodges before one is eventually chosen as the lodge they will winter in. Maintenance consists of adding more sticks and mud to the lodge to increase its size and strength. This behavior is strong until early October (leaf-fall) when lodge maintenance tapers off and food pile construction begins. They begin the food pile by placing woody branches and other food items at or near the base of the lodge and continue adding until ice-up.

HABITAT REQUIREMENTS
Water

Beaver must have a reliable source of water. Intermittent streams or ponds are not suitable. Although beaver may attempt to colonize intermittent sources early in the season, they will abandon them later if they prove inadequate. Many beaver colonies are established in summer. One reason may be that the amount of water in spring is a poor predictor of the adequacy of water later in the season. Abnormally low river water in late summer or early fall can also create problems for beaver. When beaver attempt to construct dams under these conditions, the return of normal or above normal flows can destroy their efforts.

An estimate of the adequacy of water resources can be obtained by considering the normal precipitation pattern, the evaporation rate, soils, and the watershed area. With these inputs, a model can be constructed to determine the upper limits of a watershed where conditions are no longer suitable for beaver. The same inputs can also be used to define where flow rate and volume of water in rivers becomes too great. Alternatively, Verry (1985) has determined that the specific conductivity of water is a useful predictor of the reliability of water supplies.

Vegetation

The character of shoreline forest vegetation is a useful predictor of habitat suitability for beaver. Several studies have shown that the presence of hardwood vegetation on shorelines is positively correlated with the presence of beaver families. Slough and Sadlier (1977) reported that the length of shoreline in nonproductive brush and in particular aspen explained 90 percent o the variability in the number of colony sites on lakes Similarly, the length of nonproductive brush or swamp stream shoreline explained 40 percent of the varia bility in the number of colony sites on streams. Thu food variables explained much of the variation on both lakes and streams.

Howard (1982) provided models in which the per centage of hardwood vegetation, watershed size, and stream width had positive effects, while increasing stream gradients and soil drainage had negative effect on the number of active colonies. These models wer 75 to 80 percent reliable in classifying beaver habita and 90 to 95 percent reliable in predicting the presenc or absence of beaver. In addition, their food habit suggest that the presence of aspen, aquatic macro phytes, and emergent vegetation would enhance th probability of the occurrence of beaver, while the pres ence of only conifers would discourage them.

Physiography

Extremes in physiography can be detrimenta Stream gradients greater than 12 percent provid questionable beaver habitat. Retzer (1955) estimate that stream gradients in the range of 0 to 6 percen were best. Yeager and Rutherford's (1957) observa tions of dam breakage where stream gradients ex ceeded 6 percent and where the width of the valle was less than 150 feet, support this assertion. Als supportive is that others found few families whe stream gradients were greater than 3 percent (Smit 1950, Hodgdon and Hunt 1966, Shelton 1966).

IMPOUNDMENT PROBLEMS

The preceeding information should suggest by th time that the habitat requirements of beaver are near guaranteed by creating waterfowl impoundments, e cept on streams flowing through closed-canopy conif stands. However, the presence of beaver *per se* do not create problems in waterfowl impoundments. fact they could be considered an asset. The proble lies with their innate repair behavior.

Under natural conditions, dam repair behavior crucial to their survival. Thus it is not surprising th it is a strong, tenacious behavior. However, in the se ting of an artificial impoundment, this behavior ca raise havoc with water level management plans. Mo water control structures are not adequately design to prevent or reduce potential beaver problems. Th both at full pool and especially at drawdown, beav are likely to create problems. In particular, they pe ceive the water flowing through the structure to be "leak" that must be "repaired".

A beaver's perception of a "leak" is based on several stimuli. In particular, the sound of running water is a potent stimulus to the release of repair behavior (Wilsson 1971, Hartman 1975). In addition to audible stimuli, Richard (1967) believed tactile and movement stimuli elicited and directed repair behavior. It is also likely that the sight of escaping water is an operative stimulus. Thus any water level control structure that (1) produces a sound of running water, (2) produces the appearance of escaping water, (3) produces the feel of escaping water, and (4) is accessible to beaver, will elicit repair behavior.

Water Control Structure Designs

Designs of water control structures are varied. Only some have been designed taking beaver problems into consideration, as the following discussion shows.

Straight Culvert

Straight culverts are very prone to beaver problems, because water leaving the impoundment is visible, it creates the sound of running water, and it is accessible. The beaver's response is to plug the culvert with sticks, rocks, and mud. Thus this design is undesirable for controlling water levels at both full pool and at drawdown.

Spillway

A fixed spillway, with or without an apron, is prone to beaver problems for the same reasons as for culverts. The beaver's response is to build a dam across the spillway entrance. So without modification, this is also an unsatisfactory design at full pool. Because a culvert is typically used for drawdown, there are also problems during this stage.

Adjustable Overflow

In this design, the water level is controlled by placing boards (also called "stop-logs") in a channeled framework within the dam. In spite of the narrow edge where the water is flowing over the boards and the immediate drop off on the upstream side of the boards, this design is also prone to beaver problems for the same reasons as the above. Again, the beaver's response is to plug the overflow with sticks and mud at both full pool and at drawdown.

Drop-Tube or Riser

This is "L"-shaped and is typically constructed with culvert sections or concrete. It has a horizontal segment beneath the dam and a vertical segment attached at or near the intake end of the horizontal segment. The water drops down the vertical segment thus its height controls the water level. Beaver plug the overflow with sticks and mud and it is very difficult to clean out. It is prone to problems at both full pool and at drawdown.

Whistletube

This resembles a drop-tube or riser, only the vertical segment does not function as a drop-tube outlet, but contains channels in which boards or stop-logs are placed to regulate the water level. Thus water flows out from the bottom of the impoundment into the horizontal segment, then up one half of the vertical tube, over the highest board, and drops down the other half of the vertical tube to flow out. The vertical portion is positioned in the earthen dam to provide access for adjusting the level of the boards. This design is less prone to beaver problems, but beaver occasionally plug the intake end which then becomes difficult to clean out. At drawdown, when the horizontal portion becomes essentially a straight culvert, it is very prone to beaver problems.

Managing Beaver Problems

Approaches to managing beaver problems could be divided into three broad classes: population control, discouraging establishment, and regulating water levels in spite of beaver.

Population Control Methods

If control is desirable and regulations allow it, the following methods can be used to remove beaver. (These deal only with the current nuisance and do not address the potential for recurring problems).

Trapping.--In general, removing beaver with steel leg-hold traps using drowning sets, or with the Conibear 330[1] (Hill 1976, Hill and Gardner 1978), is the most practical way in the hands of competent trappers (Almand 1976, Hicks 1977, Jackson 1978, Miller 1977, Peterson 1979, Van Hoey n.d., Woodward *et al.* 1976). Using Hancock or Bailey live-traps for beaver is another alternative (Buech 1983, Taber and Cowan 1969), but these traps are more expensive.

Shooting.--This method is usually ineffective because of beavers' nocturnal habits, the time required to be in the right place at the right time, and because swimming beaver present a difficult target (Hicks 1977, Van Hoey n.d., Woodward *et al.* 1976). However, it can be effective in fall, when beaver are more active during twilight hours.

Miscellaneous.--Other methods have been used but are too specialized or not appropriate for various reasons. Although several poisons appear effective, none are approved for use (Hicks 1977, Hill 1976). Alligators may reduce--but probably do not eliminate--beaver populations (Arner *et al.* 1981, Hicks 1977). Trained dogs can be used to flush beaver from lodges

in drained ponds so they can be shot (Hicks 1977, Woodward *et al.* 1976). Several chemosterilants appear promising as antifertility agents (Gordon and Arner 1976), but the details of practical application have not been solved.

Discouraging Establishment

Techniques that have been tried for discouraging establishment or encouraging them to move out are many, but most are not effective.

Removal of dam, lodge, or both.--This procedure is probably the most used, but least effective method (Almand 1976, Guenther 1956, Hicks 1977, Miller 1977, Van Hoey n.d., Woodward *et al.* 1976). Typically, one or both are removed or partially destroyed either manually or with dynamite. The usual response is a repaired dam or lodge by the following day. Removal is most successful during the initial building period. Its effectiveness can be enhanced by complete removal of the dam and lodge, including removal of the building materials far enough from the site so they cannot be reused. however, even if you are successful, there is no assurance that another family will not try to settle later on.

Habitat alteration.--Land clearing to remove food resources has been tried with only limited success (Hicks 1977). If building material is scarce, complete removal of the remaining woody vegetation can be effective, *e.g.*, along ditches, canals, streams, ponds, and reservoirs in sparsely forested areas (Byford 1974, Miller 1977, Woodward *et al.* 1976). Alternatively, although it would take some time before it would be effective, the shorelines could be densely planted to conifers to shade out hardwood vegetation.

Repellants.--Various repellants have been tried to discourage repair behavior or feeding on valued trees. Huey (1956) reported 10 percent trinitrobenzene-aniline in acetone with arochlors to be the most effective for preventing damage to valued trees of four chemical repellants tested. Hicks (1977) reported that the deer repellant "Magic Circle" appeared promising. A new repellant, called "Ropel" (Atomergic Chemetals Corp., Plainview, NY), whose active ingredient is denatonium saccharide, has been advertised recently as an effective means of preventing beaver from cutting or feeding on vegetation. Other common chemicals have been tried with no success (Guenther 1956, Hicks 1977). Other repellants such as light and noise devices had little or no lasting effect on beaver repair activity (Guenther 1956, HIcks 1977, Van Hoey n.d.). I have tried wind-activated wolf silhouettes and wolf feces as deterrents to plugged culverts, also with no success. However, Guenther (1956) reported success using the scent of other natural predators (bear and cougar) carried on burlap bags from caged animals. When the bags were hung over the dam, beaver temporarily avoided the area, but resumed repair when the scent dissipated.

Johnson *et al.*, (1976) tried using electrically charged wires across dam breaks, but electrical deterrence of repair behavior was not effective because the system was too easily shorted out. However, others reported success with electric "shocker" fences (Woodward *et al.* 1976, Richard Joarnt personal communication). For example, Joarnt solved the shorting problem by attaching the noninsulated wire to a frame on floats (fig. 1). This device stopped beaver at all structures while the charger was operating. They still avoided the structures after the device was removed at three of four structures.

Two other repellant methods seem worth trying. One suggested by Peterson (1979) is to create and maintain artificial scent mounds at vacant problem sites to falsely advertise that the area is already occupied. Data provided by Muller-Schwarze and Heckman (1980) suggest this may be effective, but it could be costly to maintain. Another method I think is worth trying is to apply a substance with an extremely offensive odor, such as skunk oil to the dam break and lodge interior when beaver kits are not present. If offensive enough to beaver this could cause them to vacate the site. As with removal methods, it might be more effective if applied during the initial establishment phase.

Regulating Water Levels in Spite of Beaver's Presence

There are several alternative ways to meet your water level objectives in spite of the presence of beaver

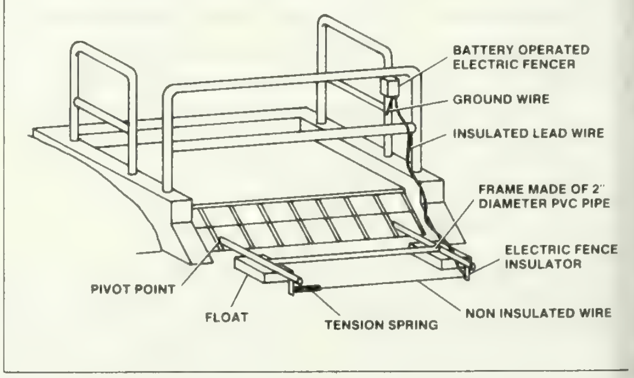

Figure 1.--*A device proposed by Joarnt (personal communication) to deter beaver nuisance behavior at water level control structures.*

[1]*Mention of trade names is for the convenience of the reader and does not constitute endorsement by the USDA Forest Service.*

Controlling the level in natural beaver ponds.--This can be accomplished by using drains of several designs. The objective in installing drains is to temporarily maintain the water at a tolerable level. Drains reduce sound and sight stimuli that trigger dam repair behavior, but they are not foolproof and may require occasional maintenance.

If scrap sheet metal is available, a "3-log" drain (fig. 2) can be effective and inexpensive (Bailey 1927). You can also use square wooden pipes with solid tops and sides and a slatted bottom, or perforated PVC pipe 16 to 24 feet long with a cap on the inlet end (fig. 3) (Almand 1976, Byford 1974, Hicks 1977, Huey 1956, Laramie 1963, Van Hoey n.d.). The drains are inserted in the dam so that one end is laid on the upstream side of the dam at the bottom of the pond and the other end extends beyond the dam on the downstream side. The outlet end of the pipe should extend far enough beyond the dam so the dam is not likely to be extended to cover it. The height of the outlet end determines the water level in the pond. Several drains may have to be installed depending on the volume of water passing through the pond.

Even so, drains don't always work. Guenther (1956) and Johnson *et al.* (1976) reported that beaver plugged the holes in perforated pipe, plugged the intake end on solid pipe, and in the case of a 3-log drain, they built a new dam above the drain. This suggests that

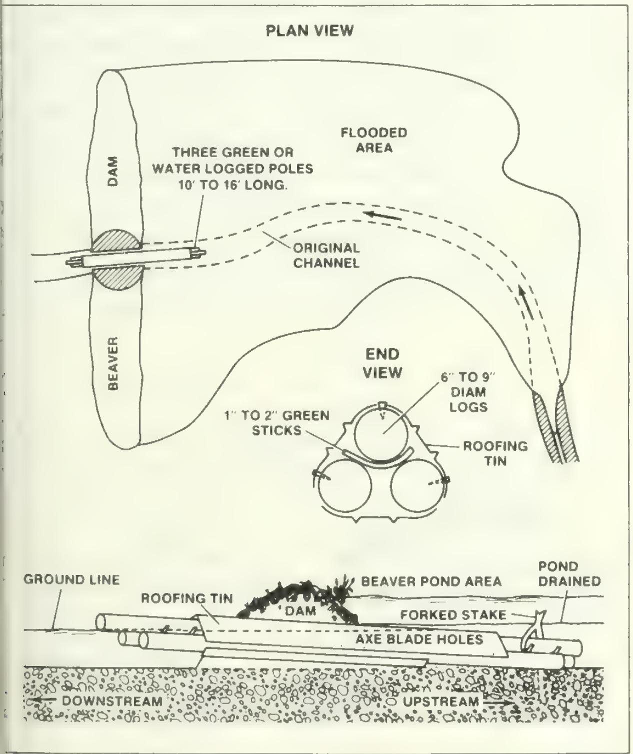

Figure 2.--*The "3-log drain" proposed by Bailey (1927) for regulating water levels in beaver ponds.*

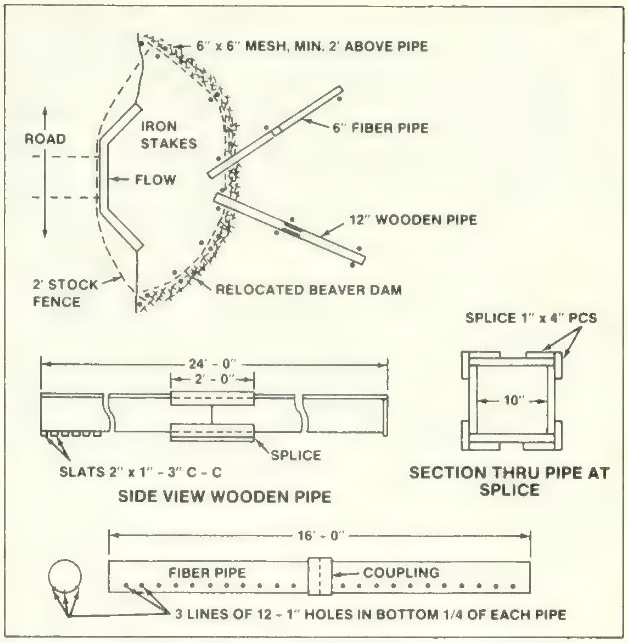

Figure 3.--*Slatted, wooden, and perforated PVC pipes proposed by Laramie (1963) for regulating water levels in beaver ponds.*

fencing or some other means of restricting access may be required to reduce tactile cues.

Guenther (1956) described a fencing arrangement that was successful for draining ponds at 16 installations over a period of 3 years. Called a "beaver baffler" (fig. 4), it consists of two parallel lines of woven wire fence about 3 feet apart extending from 15 to 20 feet below the dam, through the dam to a distance of 30 to 40 feet upstream in 1 to 3 feet of water. Woven wire cross sections are installed within the fenced lane in case beaver enter the lane from beneath the fence. Posts are placed close enough to hold the wire on the bottom.

Minimizing maintenance of existing water control structures.--Fences are particularly useful

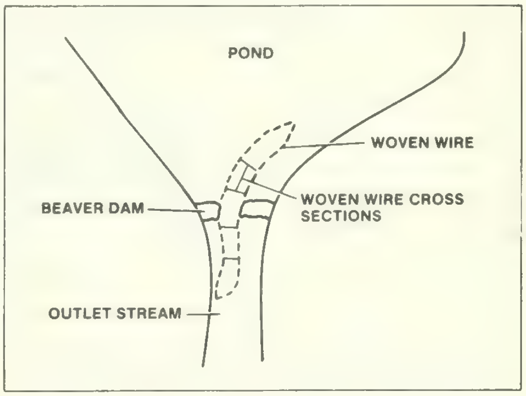

Figure 4.--*The "beaver baffler", a fencing arrangement proposed by Guenther 1956 for regulating water levels in beaver ponds.*

for reducing maintenance (Guenther 1956, Peterson 1979). Although fencing reduces the workload, it does not deter dam repair behavior; it redirects the behavior to where it is more easily handled. In this method, fencing is used to surround the intake end of culverts, spillways, adjustable overflows, or drop-tubes. Because the sound and sight of escaping water is still present, beaver respond by directing dam repair behavior as close as possible to the "leak". Because access is restricted, they attempt to repair the leak against the fence. Here, the material is easier to remove than say inside a culvert. Donald Potter (personal communication) reported he has successfully used sand bags in place of fencing in a semicircle around culvert intakes to reduce maintenance. Drains can also be used in conjunction with fences if the presence of beaver can be tolerated (Laramie 1963).

Cleaning out beaver-plugged culverts takes time. David Johnson (personal communication) reported that they use a portable, gasoline-powered water pump to hydraulically remove plugs from culverts. Laramie (1963) described another method that uses a vehicle-mounted winch for this purpose. A concrete reinforcement rod is used to thread a rope through the plug. The rope in turn is used to pull the winch cable through the plug. A short log (15 cm shorter than the culvert diameter) is attached at its center to the cable. The cable is then winched through a snatch block below the culvert outlet to pull the log and plug through the outlet end of the culvert. The log is removed, the rope is used to pull the cable back through the culvert, the log is reattached, and the process is repeated as necessary. If a mud plug remains, a small diameter tree can be winched through the culvert like a cleaning brush.

Suggestions for More Permanent Solutions

To repeat a previous point, dam repair is an innate behavior that is triggered and directed by acoustic, visual, and tactile cues. So any structure that permanently solves problems with beaver must control the water level without the sound, sight, and feel of escaping water. As a preventive measure, it should also restrict access to the structure, especially if the feel of escaping water still exists.

I offer the following suggestions solely on the basis of my understanding of beaver behavior, not because I have implemented them. However, I believe each of these should reduce the stimuli that trigger repair behavior and therefore should reduce or eliminate beaver problems.

Culverts

Culverts are very prone to beaver problems becaus they produce the sound, sight, and feel of escapin water and are accessible. One potential solution fo eliminating these cues might be to attach a short elbo on the intake end of the culvert facing down, with grate over the opening (removable for cleaning). Th immediate area of the elbow should be dug out wit a backhoe or other heavy equipment to create a dee hole directly below the intake end of the elbow. Thi should remove visual cues and reduce acoustic cue and access, but it's not foolproof. (1) Sound would onl be attenuated, especially if the water level is controlle by the height of the intake end of the culvert. (2 Beaver would still be able to feel escaping water at th elbow. And (3), although modifying the intake end most important and probably sufficient, beaver migh start repairing the outlet end of the pipe by pluggin the pipe directly, extending the dam to include th pipe, or building a new dam below the outlet. Th sound of escaping water can be moved to the outlet the culvert by using this end to control the water lev (although this may impede fish movement). Repa activity would be less likely on the outlet end.

On the upstream side tactile cues could be reduc at the elbow by further restricting access to a distan far enough from the intake that they can't feel a current. Observations by Reynolds and Lewis (197 and Guenther (1956) suggest this is probably nece sary. They reported instances of beaver mounding mud and debris until it eventually reached one intak even though the intake was 3 m above bottom. R stricting access can be done by fencing, staking, caging the intake or enclosing it within a pile of roc I would recommend trying the latter as in figure 5. a problem develops at the outlet end, the same elb treatment could be applied there as well, or the out could be extended, grated, or fenced.

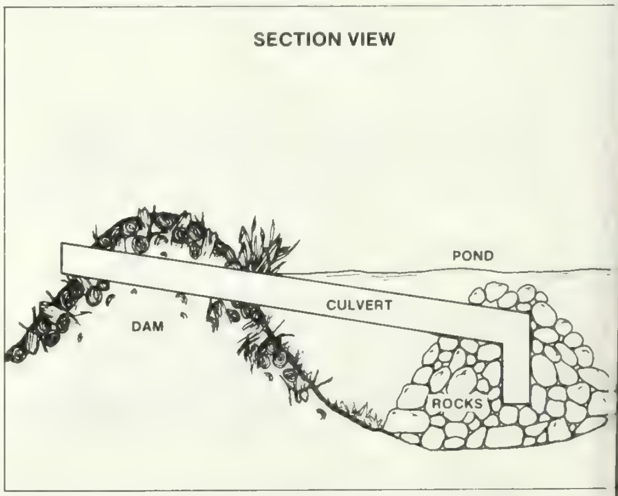

Figure 5.--*A proposed culvert treatment for reduc problems with beaver.*

Another culvert treatment that I tried successfully t one colony was to cover the intake of the culvert vith a sheet of plywood so the lower edge was just elow the water surface. This removed the appearance f escaping water from the upstream side, although he water was in fact freely flowing out through the ulvert. By removing and replacing the plywood, I was ble to turn their culvert plugging activities on and ff. However, the flow rate of the water was very low, he opening below the plywood was too small for a eaver to enter the culvert, there was little to no sound f water running out the culvert, and there was absolutely no visual cue on the pond surface that water vas escaping. Thus this technique may have limited se. It also requires checking and adjustment because t restricts the flow of water (which would be important if the flow rate increased) and it would fail if the vater level dropped below the plywood.

Spillways and Adjustable Overflows

Because both of these designs produce the sound, ight, and feel of escaping water, any solution must educe or eliminate these cues, restrict access, or both. My inclination would be to try installing a vertical affle off the leading edge of the overflow or spillway o that from the water surface on the upstream side, scaping water would be invisible. Baffle height and ength should be sufficient to prevent a view of the scaping water and access to the spillway or overflow. The gap between the leading edge of the spillway or verflow and the baffle should be sufficient for the olume of water anticipated, sufficient to prevent substantial sound of water passing up through the gap, et too small for a beaver to pass through. A gradual ecline from the spillway to a pool rather than a verical drop over the edge would help reduce the noise f escaping water and therefore attract less attention. Also, it would be desirable to restrict access by staking r fencing the area in front of the baffle, far enough way so that water cannot be felt passing through the arrier.

Drop-tubes or Risers

The drop-tube produces all the stimuli that trigger epair behavior. Aside from temporarily restricting acess with fencing, one possible solution would be to dd two successive 90° elbows to the intake with a emovable grate over the opening so as to create an verted "J". In this configuration, the intake would e below the water surface and therefore eliminate the ppearance of escaping water. The report of Reynolds nd Lewis (1976) suggests that this may be adequate. lowever, the sound of escaping water still would be resent because the water is falling down the dropbe. If sound continues to attract attention, a length pipe could be installed between the 90° elbows to move the intake far enough from the sound of the water dropping down the vertical tube so they are not as likely to associate this sound with the intake. In either case, it may be necessary to restrict access to the intake by fencing, staking, caging, or enclosing in a pile of rock so that beaver cannot get close enough to feel the escaping water.

Whistletubes

At full pool this design reduces beaver problems, but it is especially prone to them at drawdown. At full pool they apparently still feel the water escaping and plug the intake end, even though sight and sound are absent. The elbow treatment recommended for straight culverts could be applied here along with fencing them far enough away from the intake to eliminate tactile cues. Or, the intake could be buried in a large enough pile of fieldstone so they cannot feel the escaping water (fig. 6). The pile of rock could also be used to form the base for a "push-up" nesting island. This treatment might solve the problem at both full pool and at drawdown.

SUMMARY

1. Waterfowl impoundments generally provide good beaver habitat by meeting their food and water requirements, especially if the shoreline contains hardwood vegetation or aspen, emergents, or aquatic macrophytes in particular. Closed-canopy conifer stands provide poor habitat, thus the only means of making impoundments unsuitable is either to remove all hardwood vegetation (reports give mixed success) or plant a dense stand of conifers. Although hardwood removal has limited applications, establishing dense conifer stands could provide a permanent solution at problem sites.

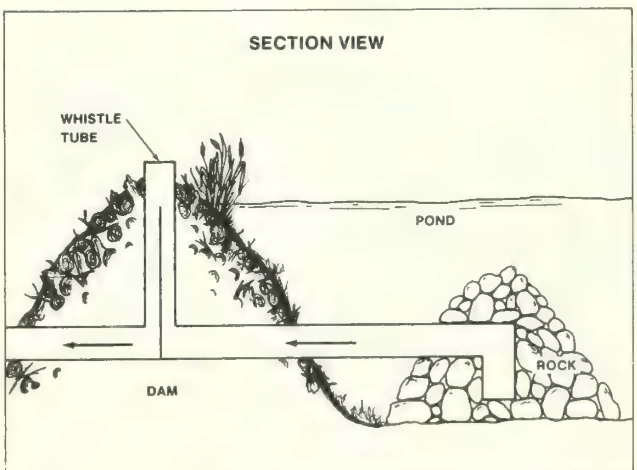

Figure 6.--*A proposed treatment for modifying whistletubes to reduce beaver problems.*

2. Impoundments under 80-100 acres are likely to contain only one family of beaver. The average family contains about five individuals; adults, yearlings, and kits each comprise about a third. Family size averages 3 to 4 individuals in exploited populations.

3. Problems at waterfowl impoundments first occur during April to May or August to September. This is because 2-year-olds diperse soon after spring breakup and families move either before the kits are born or after the kits are weaned. If beaver already occupy an impoundment, problems are likely to intensify as their interest in dam and lodge maintenance increases in August to September. Few if any new problems occur after September.

4. If the impoundment has abundant food resources, beaver families are likely to stay for a number of years. Trapping pressure or low food resources can reduce their stay; often to only a year.

5. Beaver in waterfowl impoundments interfere with the function of water control strurctures. This results from their repair behavior that is triggered and directed by the sight, sound, and feel of flowing water. Thus beaver-proof water control structures must function without producing these cues.

6. Water control structures have five basic designs: (1) Straight Culvert, (2) Spillway, (3) Adjustable Overflow, (4) Drop-tube or Riser, or (5) Whistletube. The inadequacies of each are discussed in relation to the cues produced. Currently, none is adequate to prevent beaver problems.

7. Beaver can be managed by population control, discouraging establishment, and regulating water levels in spite of beaver. Population control methods are only temporary. Methods available for discouraging establishment in forested areas are generally inefffective and probably temporary. The best approach, if solutions can be found, is to design water control sturctures that are beaver proof. This would permanently avoid maintenance problems.

8. Methods for controlling the water level in natural beaver ponds are reviewed. Drains and fencing are useful alternatives for temporarily managing a problem site, but both require maintenance. Suggestions on how to reduce the production of cues that trigger repair behavior are offered for the five basic designs, though none have been tested in the field.

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MANAGING WATERFOWL IMPOUNDMENTS FOR FISHERIES

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"In prehistoric times, Wisconsin was dotted with great numbers of extensive sphagnum bogs. Most of them are now dead and are preserved in the form of great flat peat lowlands varying in extent from a few hundred acres up to many square miles. Unlike the living peat bogs, the soil and consequently, the water, in these lowlands is sweet, and in damp places, productive of pond weeds, tuber-bearing plants, and wild rice. In many places, the peat is underlain by marl or blue clay, but even where there is nothing but sand, the state of decomposition of the peat is such as to be productive of numerous forms of duck foods. Most of these areas are too wet to be of value as agricultural lands and too dry for ducks, Drainage projects have been established in some areas at great expense. Many of these have been unsuccessful. That these areas have potential waterfowl breeding and feeding value has been proved in instances where flooding has been tried.... water-level restoration in these areas is needed, not only as an emergency duck measure, but in a far-sighted program for duck marsh conservation."

These were comments made by Homer T. Sowls and John T. Emlen, junior engineer and junior biologist, respectively, in 1934, as field crew for a Wisconsin marshland survey conducted under the supervision and counsel of Aldo Leopold and M. D. Pirnie. Sowls and Emlen felt many of the areas they had surveyed could be improved for waterfowl by building relatively small, inexpensive dams to raise and control water levels. Some areas that had no flowing stream or no good dam site would require excavation of channels and ponds.

They had observed old mill dams on some sites and had learned from local residents that when flooded, these areas were heavy duck breeders and good "pickerel" lakes. They also observed carp in the river systems of the marshes surveyed and expressed concern that carp would affect the growth and spread of vegetation, and even constitute a threat to low impounding structures.

The survey of 1934 made note of the two basic fish management issues still of consequence to fish managers today; managing waterfowl impoundments for game fish, and managing waterfowl impoundments to control rough fish.

The surveys terminated with management recommendations for each area having promise. Their reports included:

1. location of the area
2. general description
3. ownership and land values
4. history of water level manipulations
5. reflooding and water supplies
6. game values
7. local sentiment
8. recommendations and alternatives
9. limitations.

CURRENT MANAGEMENT CONSIDERATIONS

Master Plans

In the mid-70's, the Wisconsin Department of Natural Resources instituted a master plan process for state properties. It was reasoned that these properties provided opportunities to satisfy a variety of public interests. Public pressures were increasing and it became imperative that we maximize user opportunities. Master plans were to be prepared for each property to ensure its basic purpose was achieved and that other public uses consistent with that purpose could be accommodated. Master plans reflect the public interest in all ecological, economic, and social benefits that may be derived from a particular property, consistent with its resource capabilities and the statutes or other constraints under which it was acquired.

Master plans are structured somewhat similar to the old marshland survey plans:

1. goals, objectives, and additional benefits.

2. recommended management programs
3. background information
4. resource capabilities and inventory
5. management problems
6. recreation needs and justifications
7. analysis of alternatives.

Environmental Impact Statements

The Wisconsin Environmental Policy Act (WEPA), which became effective in 1972, requires that an environmental impact statement be prepared for any major action that significantly affects the quality of human environment. These statements closely follow guidelines issued by the U.S. Council on Environmental Quality.

Actions of lesser significance require an environmental impact assessment. Both are subject to public review, constituting another process whereby those who use the resource participate in its managment.

Impact statements repeat most elements of a master plan, though the emphasis may be somewhat changed:

1. introduction containing the proposed action, purpose and history of the project
2. details of proposed action and identification of alternatives
3. description of the affected environment; physical, biological, social and economic
4. consequences of the proposed action on each part of the environment
5. alternatives to the proposed action.

WATERFOWL IMPOUNDMENT MANAGEMENT

Goals and Objectives

Waterfowl impoundments may commonly be features of a public property being managed for its maximum potential as a waterfowl area, primarily for ducks, while providing hunting, trapping, fishing, education, and other compatible recreation opportunities. In other instances, the goal may be restated to manage, preserve, and protect the fish and wildlife resources and their habitats for optimal fish and wildlife based recreation, education, and production, consistent with property capabilities. Regardless of the exact goal statement, it is readily apparent that fish and fishing are considered valid resources of a waterfowl impoundment.

Specific objectives for impoundment management are normally quantified:

1. to produce 0.6 ducklings per acre
2. to provide ____ hunter days
3. to provide ____ trapper days
4. to harvest ____ muskrats (3/ac)
5. to provide ____ dog trial/training days
6. to maintain breeding populations of ____ species
7. to provide ____ angler days
8. to provide ____ participant days of hiking, etc.

Examples of specific objectives for several Wisconsin impounded wildlife areas are provided in table 1. It is well to note that no direct relationship exists between impoundment size, total user days, and angler days.

At this point, the true capability of the impoundment is evident. If the property manager has assessed local interest, existing conditions and resource capabilities, the objectives will reflect this and provide targets to satisfy public interests.

Management is usually a team effort, involving wildlife manager, fish manager, forester, warden, etc. The fish manager, who normally quantifies the fish management objectives for the impoundment, will be quick to recognize those problems associated with reaching his objectives.

Problems and Strategies

Exotics

Carp adversely affect fish objectives as well as waterfowl objectives. They discourage establishment of waterfowl food plants by their bottom feeding behavior. They create turbid water conditions, which, in turn, limit the success of more desirable sightfeeding predator fish, and reduce light penetration essential for growth of vegetation. Carp may physically displace more desirable fish by simply competing with them for space.

Table 1.--*Specific management objects for three Wisconsin wildlife areas with waterfowl impoundments*[1]

Activity	Sheboygan marsh	Horicon marsh	Grand river marsh
Waterfowl hunting	3,500	20,000	12,000
Deer hunting	4,000	3,000	1,500
Other hunting	1,300	3,700	1,750
Trapping	1,000	4,000	1,500
Fishing	4,000	3,000	2,500
Snowmobiling	4,000	3,000	500
Hiking, viewing, etc.	4,000	24,300	3,000
Total	13,800	61,000	22,750
Water area	1,000 acres	6,000 acres	3,000 acres

[1]Expressed in annual user days, based on Department of Natural Resources Master Plans.

The most effective strategy is to chemically eradicate the entire fish population, to prevent reinfestation by using barriers, and to reintroduce desirable fish species. Chemicals most commonly employed are rotenone and antimycin. Rotenone has been most effective when applied immediately before freeze-up. This allows the toxin to take effect and still detoxify while the entire water body is under ice cover.

Impoundments that are regularly drawn down provide an opportunity for controlling re-entry of carp by using either mechanical or electrical barriers alone.

Commercial harvest of carp from waterfowl impoundments has been practiced since the 1920's. Harvest from a single impoundment may be hundreds of thousands of pounds annually. Generally such harvest is ineffective in eradicating or even significantly reducing the carp population. Carp removal with nets may disrupt aquatic vegetation and decrease the attractiveness of an impoundment for waterfowl if done at inappropriate times.

Often the property manager is confronted with rough fish harvest as an objective which does not contribute to the original goals of the management plan.

Low Oxygen Levels

Low oxygen levels (3 mg/l) may favor carp, bullheads, and green sunfish, but eliminate more desirable game fish such as bass, bluegill, and northern pike except during the seasonal migrations to the impoundment for spawning.

Maintaining sufficient oxygenated water in shallow water bodies is both difficult and costly. It may be possible to dredge pockets and channels to provide oxygenated refugia. Dredging should be done at about 20-year intervals because the pond sediments are usually light and mobile, and organic sediments can build up rapidly.

It is also possible to aerate existing ditches and pockets. This process is effective, but costly. A single aeration station may cost as much as $35,000 to purchase and install, and $3,000/year to operate. Aeration is most effective when initiated early in the winter, however, this increases the overall cost proportionately.

Managing waterfowl impoundments at the highest possible water level throughout the year would provide the most fish habitat and highest natural oxygen levels, but would have obvious adverse impacts upon waterfowl habitat.

Dewatering Practices

Periodic partial drawdown may be needed to rejuvenate emergent marsh vegetation. On large waterfowl areas, the wind/wave action across expances of open water sometimes dislodges "islands" of marsh vegetation. Partial drawdowns are conducted every 5-7 years, depending on the rate of vegetation loss.

Partial Summer Drawdowns.--The effect of partial summer drawdowns depends to a great extent on the depth, duration, and frequency of the drawdowns. A complete drawdown over an extended time would concentrate the fish, leading to increased competition, emigration, disease, and angling mortality. More young fish would die as they are forced out of shallow nursery areas. Large predators would migrate upstream if possible. With reflooding, immigration back into the impoundment would compensate for this loss. Downstream or upstream movement of large predators during drawdown may increase predation on intolerant stream fisheries. Another negative result of drawdown would be increased winter biological oxygen demand from increased vegetation, causing more severe reduction in dissolved oxygen levels.

There are some positive effects of drawdown on fisheries. Depth may increase due to sediment compaction. Fish growth may increase during drawdown when prey are more vulnerable, and after drawdown as unoccupied habitat is reflooded. northern pike reproduction may increase as desirable vegetation is reflooded before the spring spawning period.

Full Summer Drawdowns.--These would, of course, magnify both the positive and negative impacts upon the fishery. If a full drawdown resulted in major reductions in adult fish populations at least 3 to 4 years of high water levels would be required for the fish to reach their previous population.

The most practical strategy is to have a partial drawdown for periodic rejuvenation of marsh vegetation without adversely affecting the fish population. Such drawdowns should be timed so as not to seriously affect other objectives of impoundment management.

Shallow Water in General

Waterfowl impoundments without discernible channels or pockets and that rely on seasonal runoff to maintain the water level, are not suited for fish management. Such ponds have no areas that would support fish over winter and would require annual stocking. Aeration would be of questionable value because the oxygen demand of extensive shallow vegetated areas might surpass the ability of aeration equipment.

Without sufficient watershed, shallow, poorly fed impoundments experience water level fluctuations that may be detrimental to both fish and wildlife. The watershed to impoundment ratio commonly used in designing stable waterfowl impoundments is 15:1.

MANAGEMENT CONCLUSIONS

Fish management is frequently compatible with waterfowl management. Where practicable, the mixture of management practices is mandated by public desires and Department policy. When asked to prioritize those activities that should be managed for on one large waterfowl area in Wisconsin, users interviewed produced the following list:

1. hunting upland game (birds)
2. hiking
3. bird watching
4. fishing
5. canoeing
6. hunting waterfowl
7. trapping
8. cross-country skiing
9. outdoor recreation.

Fishing holds a significant position in users' priorities. We can manage for fisheries provided the water is either deep enough or the exchange rate is great enough to provide well oxygenated winter refugia, provided measures to insure over-winter survival of fish are not too costly, provided water level manipulations to benefit waterfowl do not seriously affect fish populations, and provided that is what the public wants.

Costs of various management practices are provided in table 2. Costs are representative of several sizes of impoundments and are based on experiences in Wisconsin during the period of 1976-1982.

Table 2.--*Potential costs for fish management remedial practices*

		Experiences		
Activity	**Current rate estimates (1982)**	**Sheboygan marsh**	**Horicon marsh**	**Grand river marsh**
Aeration	$5-10,000 for compressor and pipe. $2-300/month of operation/200 acres		$35,000 Installation $3,000/operation/year.	
Fish Stocking	$1.75/1,000 northern pike at less than 100,000/acre $3.80/100 largemouth bass at 100/acre			$4-5,000/year.
Chemical treatment	$7.00/acre foot with late fall treatment (4.4° C & 0.75 pmm) at $25,000/treatment[1]			
Treatement and stocking				$10,000 (1076) $26,000 (1979)
Dredging	$1.25 - 2.00 yd³ dry or hydraulic. Dependent on proximity of disposal site and magnitude of project	$2.95/yd³	(1981)	
Electrical barrier			$15,000 installation $2,000/operation/year	$4,000 (1979)
Fish trap				$1,495 (1979)

[1]Late Fall Application Recommended Water Temp. 4.4° C.
Rates:

Alkalinity of	1- 35 ppm Tox. Conc. 0.5 ppm	100 ppm Tox. Conc. 1.00-2.00 ppm
	35- 70 ppm Tox. Conc. 0.75 ppm	Need 2 boats, 4 people/100 acres
	70-100 ppm Tox. Conc. 1.00	

CLASSIFYING WETLANDS ACCORDING TO RELATIVE WILDLIFE VALUE: APPLICATION TO WATER IMPOUNDMENTS

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Freshwater wetlands are among the most productive wildlife habitats. They produce an abundance of waterfowl species such as mallards (*Anas platyrhynchos*), ruddy ducks (*Oxyura jamiacensis*), and coots (*Fulica americana*) plus numerous songbirds such as red-winged blackbirds (*Agelainus phoenicesus*) and yellow warblers (*Dendroica petechia*). Wetlands also provide habitat for various mammalian species such as muskrat (*Ondatra zibethicus*) and beaver (*Castor canadensis*).

While wetlands are among the most productive wildlife habitats, they also are being lost at an alarming rate. Weller (1981) estimated wetland losses to agricultural and urban development at 1 to 4 percent annually. Given these trends, wetland managers could benefit from information relating to wildlife use of wetlands and wetland classification schemes for wildlife. Such information would also assist them in protecting high quality wetlands habitats and in formulating management strategies. In this paper I discuss the attributes most strongly associated with wildlife use of wetlands in north-central Minnesota and then show how these attributes can be used in two classification schemes that assess relative wildlife value of individual wetlands. These concepts can also apply to water impoundments.

WETLAND ATTRIBUTES ASSOCIATED WITH WILDLIFE USE

Considerable research has been conducted to determine what wetland attributes have the greatest attraction for wildlife. Many different attributes have been investigated. For example, Beecher (1942) and Kendeigh (1948) found bird utilization of habitat strongly correlated with vegetative structure. Hunt and Naylor (1955) also found habitat utilization by ducks correlated with certain vegetative conditions. They found that vegetative diversity and proximity to water were more important to nesting ducks than vegetative type alone.

Recent studies have stressed the importance of wetland spatial attributes. Weller and Spatcher (1965) found bird numbers and diversity in marshes strongly correlated with the ratio of open water to vegetated area. Maximum bird numbers and diversity occurred when there were nearly equal amounts of open water and vegetation ("hemi-marsh"). There is also evidence suggesting that a wetland's value as wildlife habitat is influenced by its juxtaposition to other water bodies. Golet (1972) reported that a wetland's value to wildlife is generally higher if it is located near other wetlands.

Below I describe how various wetland attributes influenced the use of 28 natural wetlands in the Chippewa National Forest, north-central Minnesota, by more than 80 species of birds. From 4 to 30 species of birds use an individual wetland according to breeding bird surveys conducted during May and June, 1980, 1981.

Size

In general, the larger the wetland the higher the number of wildlife species it can support. Figure shows the relationship between wetland size and avian species richness for wetlands in the Minnesota survey. The number of avian species increased sharply with increased wetland size but began leveling out once wetland size exceeded 4 hectares. Similar trends were reported by Probst (1979) for other avian communities.

Juxtaposition

Juxtaposition is closely associated with size. Indeed several small wetlands in close proximity can often be thought of as one large wetland complex.

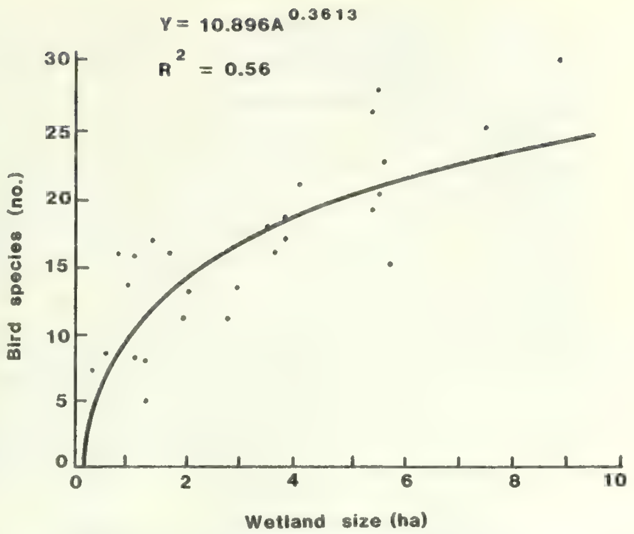


Figure 1.--*Relation between wetland size and avian species richness for wetlands in north-central Minnesota.*

Each of the 28 wetlands surveyed was classified as either "isolated" or "clustered" to determine which was used by more bird species. (Isolated wetlands were located more than 0.25 miles from 2 or more other wetlands while clustered wetlands were located less than 0.25 miles from 2 or more other wetlands). In general, clustered wetlands supported more bird species than isolated wetlands (fig. 2).

What makes wetland clusters attractive to more bird species is not clear; increased vegetative diversity may be a factor. Because wetlands disrupt forest cover and promote shrub growth, birds may be responding to greater variation in vegetative structure. Two to three different wetland types close by each other seem to create the heterogeneity in avian breeding and feeding areas needed to maintain high species diversity (Weller 1978).

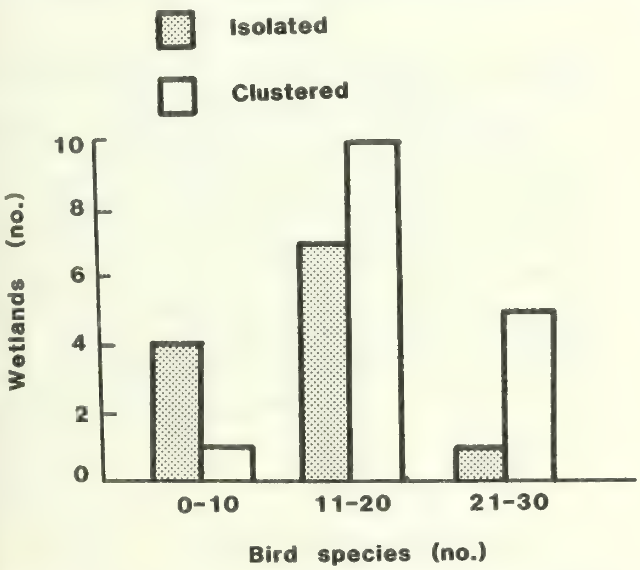


Figure 2.--*Relation between wetland clustering and avian species richness for wetlands in north-central Minnesota.*

Plant Community Richness

My work in the Chippewa National Forest suggests that plant community richness (i.e. the total number of plant communities occurring within or immediately adjacent to a wetland) influences use by birds. Plant community descriptions adopted for this study were provided by Cowardin and Johnson (1973).

While the number of bird species was found to increase with the number of plant communities present (fig. 3), the number of species levels off rapidly to about 15 in wetlands having 7 or more plant communities.

Additional evidence that the diversity of plant communities influenced use by birds was found in the wetland perimeter. Pine (*Pinus* sp.) stands are less vegetatively diverse and provide fewer breeding and feeding sites. Thus the number of bird species declined where pine stands dominated more than 25 percent of the wetland perimeter (fig. 4). Bird species were most numerous where mixed hardwoods or aspen (*Populus* sp.) surrounded the wetland.

Snag Abundance

Snags are generally recognized as an important component of forest avian habitats. Scott *et al.* (1977) estimated that about 85 species of North American birds either nest or roost in dead or deteriorating trees. In addition, many other species utilize snags as perches or feeding sites.

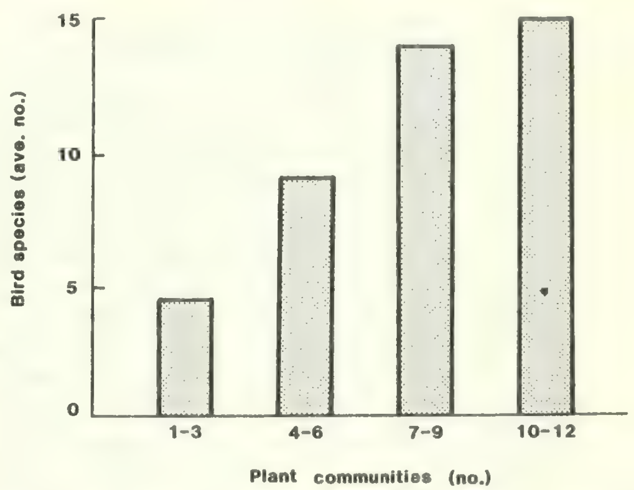


Figure 3.--*Relation between plant community richness and avian species richness for wetlands in north-central Minnesota.*

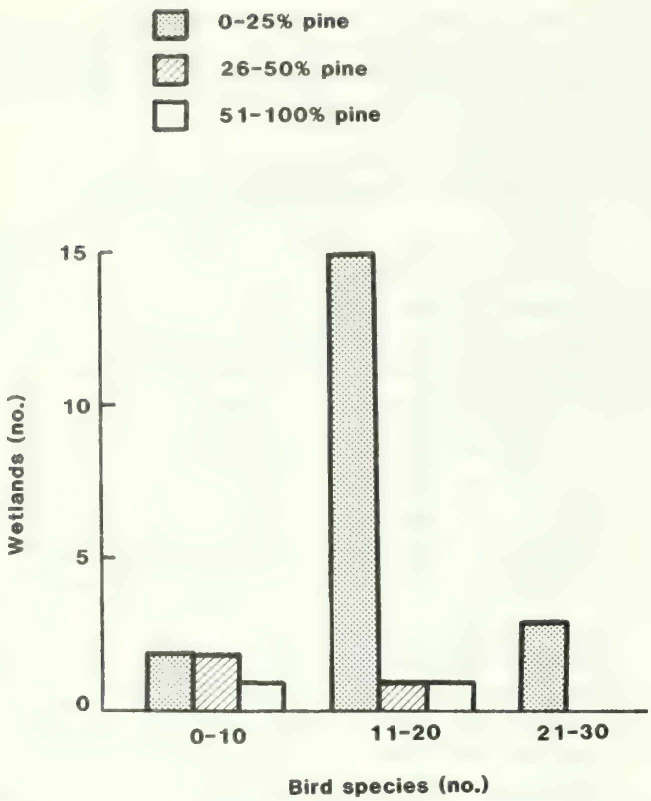


Figure 4.--*Relation between percent pine perimeter and avian species richness for wetlands in north-central Minnesota.*

Given the importance of snags to many species, it seemed plausible that avian species richness would be associated with wetland snag abundance. This was indeed the case. In general, the number of bird species was higher in wetlands having more than three snags per hectare (fig. 5).

Water-Cover Ratio

Some investigators (Weller and Spatcher 1965, Golet 1972) have suggested that the ratio of open water to vegetated surface area influences wetland wildlife. My results show some agreement with these findings but they also suggest that water-cover ratio may be less important in forested areas than in others. For example, of the 7 wetlands in my survey providing habitat for 20 or more avian species, 5 (71 percent) had wetland cover types 4 or 5, the types assigned greatest wildlife value in Golet's wetland classification scheme. Because these cover types have cover plants occupying 26-75 percent of the wetland area, these findings are also in agreement with those of Weller and Spatcher (1965). However, if all 28 wetlands are included, there is no significant relation between avian species richness and percent open water (fig. 6.)

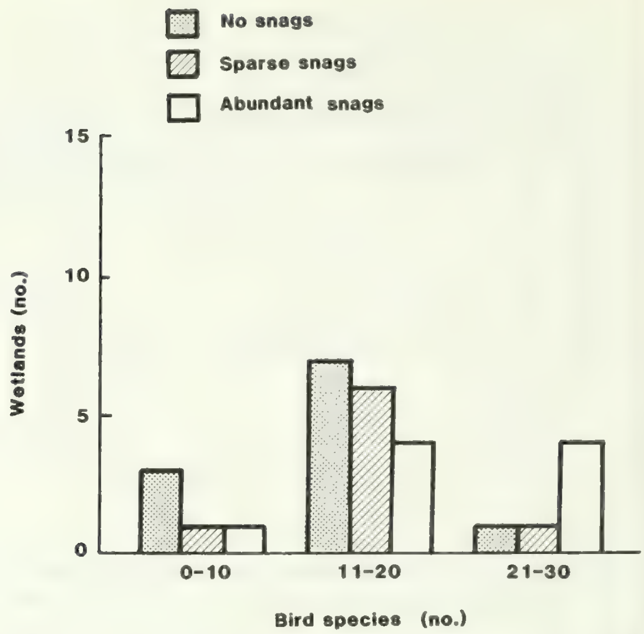


Figure 5.--*Relation between snag abundance and avian species richness for wetlands in north-central Minnesota.*

The weak association between water-cover ratio and species numbers in my survey may reflect the nature of the wildlife community. Golet (1972) designed his wetland classification scheme to evaluate habitat for water-dependent species such as waterfowl and muskrat. Likewise, Weller and Spatcher's (1965) findings reflected habitat selection by marsh birds. Because passerines made up a large percentage of the wildlife community I investigated, one might logically expect to find a weaker association between water-cover ratio and species numbers.

Water Permanence and Chemistry

Water permanence and chemistry are two other wetland attributes used by Kantrud and Stewart (1977)

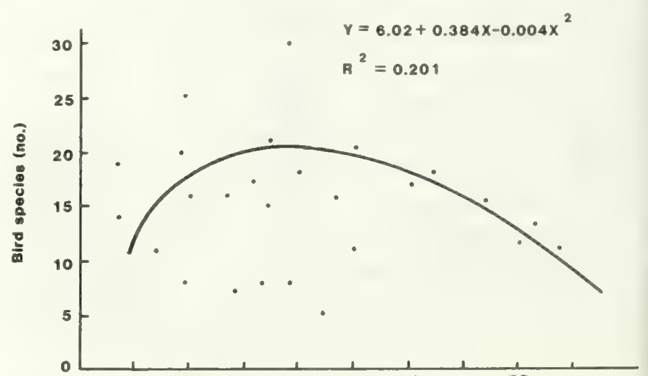


Figure 6.--*Relation between water-cover ratio and richness for wetlands in north-central Minnesota.*

in their studies of waterfowl use of prairie potholes in North Dakota. They found that waterfowl displayed strong affinity for those potholes that were seasonally flooded, presumably the result of higher aquatic invertebrate populations (Swanson and Meyer 1977). Similarly, water chemistry measurements such as pH and conductivity are also used to assess wetland wildlife value (Wheeler and March 1979).

I found neither water permanence nor water chemistry (pH and conductivity) strongly associated with numbers of bird species for wetlands in the Chippewa National Forest. Again, these findings may reflect the fact that waterfowl species represented only a few of the species in the wildlife community I investigated.

METHODS OF ASSESSING RELATIVE WILDLIFE VALUE OF WETLANDS

We have identified some important ecological conditions that influence wildlife use of wetlands. This is important information for management and planning but the manager may be more interested in knowing how alterations (e.g., changing water-cover ratio) increase or decrease the wildlife use of that wetland. For this, we must employ a quantitative scheme that gives a measure of the wetland's value to wildlife based on ecological variables. Several such schemes have been proposed but I will restrict my discussion to two such schemes, one developed by the U.S. Fish and Wildlife Service (FWS) and the other by the U.S. Army Corps of Engineers (COE). These two systems appear to have widest applicability and therefore offer greatest potential assistance to the impoundment managers.

Major Assumptions

Both the FWS and the COE habitat classification schemes are based upon two assumptions. The first is that the quality of fish and wildlife habitat can be expressed as a numerical index that reflects biotic and abiotic conditions associated with a given wetland. The second assumption is that habitat numerical scores give a general indication of habitat carrying capacity. Habitat suitability indices then are generally thought to express the relation:

$$\text{Habitat Quality Index} = \frac{\text{Populations Associated with Current Habitat Conditions}}{\text{Populations Associated with Optimal Habitat Conditions}}$$

Fish and Wildlife Service Method

Since 1974, the FWS has been developing and refining a set of quantitative procedures land managers can use to assess wildlife habitat quality. The procedures, called Habitat Evaluation Procedures (HEP), have been used most extensively by land managers to assess wildlife impacts arising from land-use changes but they could be used equally effectively to develop wetland management strategies.

The FWS system computes a habitat suitability index (HSI) for a particular habitat from habitat suitability models developed by wildlife biologists. These suitability models are typically developed for individual wildlife species and consist of a collection of curves, each curve depicting the functional relation between a given habitat attribute and habitat value for that wildlife species. As an example, the curves comprising the habitat suitability model for wood ducks (*Aix sponsa*) are provided in figure 7. Once the manager has inventoried a given wetland, he can use these curves to assess the wetland in terms of (1) food value, (2) aquatic habitat value, (3) cover value, and (4) reproductive value for wood ducks. Building upon the concepts of limiting factors and habitat quality, relative habitat value will be the smallest of these four values.

To better understand how the HEP system is applied, let us consider a hypothetical set of wetland attributes (table 1). The computations associated with our example illustrate that the lowest suitability index (0.79) is associated with reproductive value of the wetland. Thus, reproductive requirements are most limiting and we consequently assign this particular wetland a relative value (on a scale of 0.0 to 1.0) of 0.79.

While our example deals with a single wildlife species, the FWS system allows managers to combine assessments for several wildlife species into a single, overall habitat assessment. The basic idea is to compute the total number of "habitat units" represented by the habitat. One habitat unit equals 1 hectare of habitat having an HSI score of 1.0 (i.e. a habitat capable of supporting maximum population densities). We obtain total habitat units by multiplying the HSI value times total habitat size and summing the products for all wildlife species. To illustrate, if the wetland habitat we considered above were 200 hectares is size, it would represent 158 (200 times 0.79) habitat units for wood ducks. If similar computations revealed that the area also provided 160 habitat units for mallards, 105 habitat units for

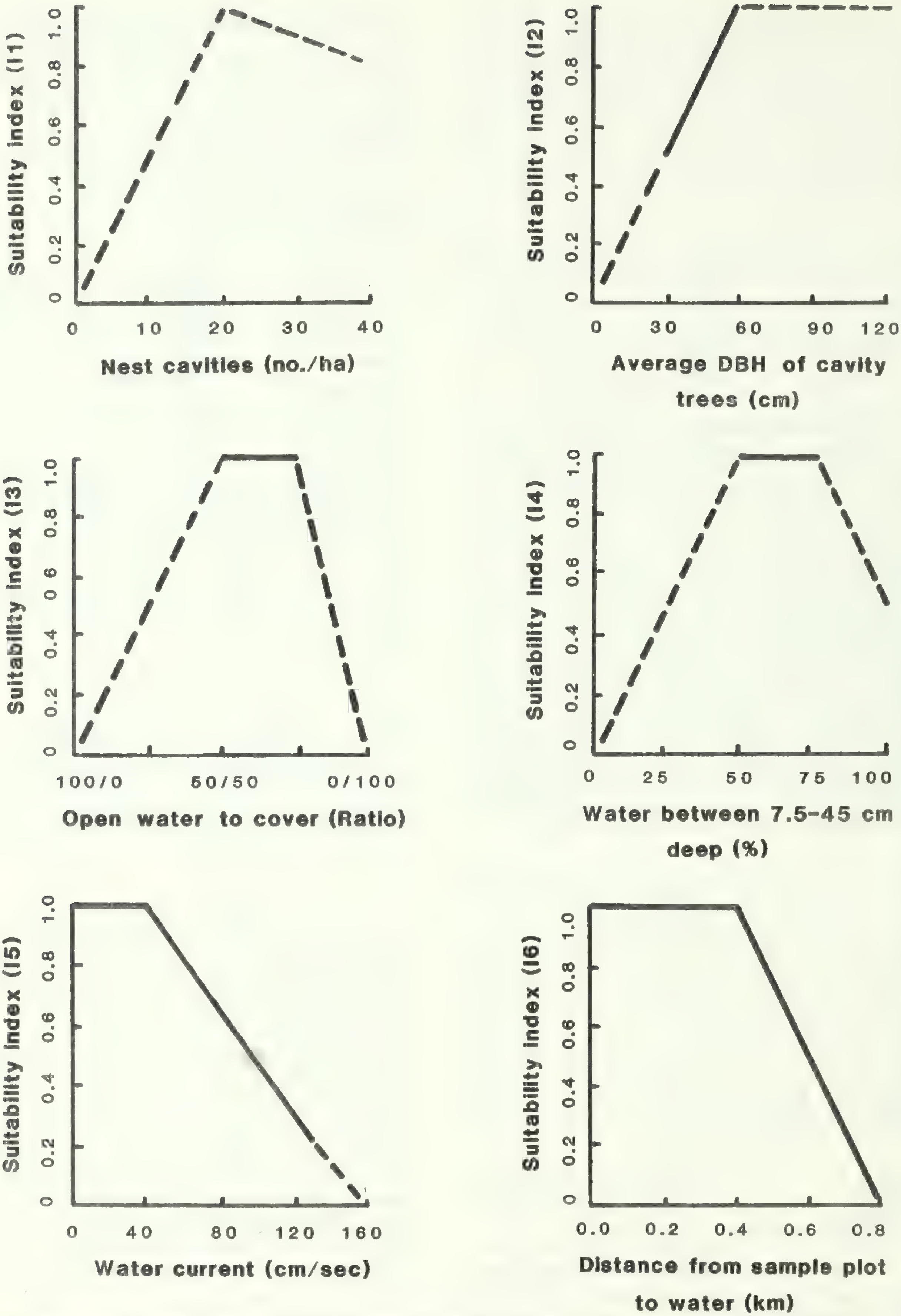
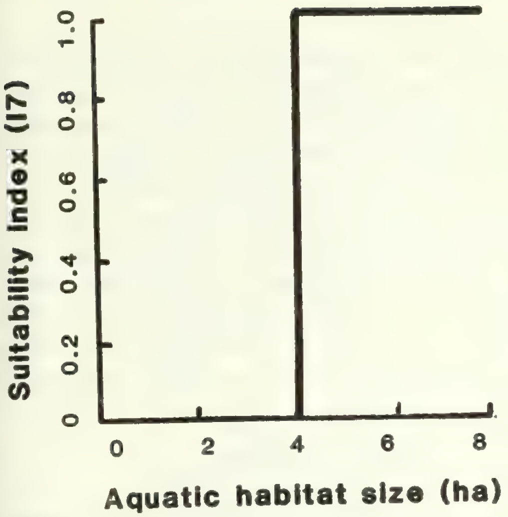
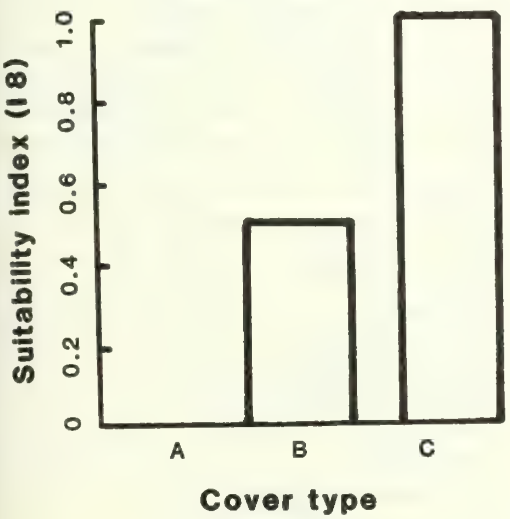


Figure 7.--*Functional curves developed by U.S. Fish and Wildlife Service to evaluate wood duck habitat.*

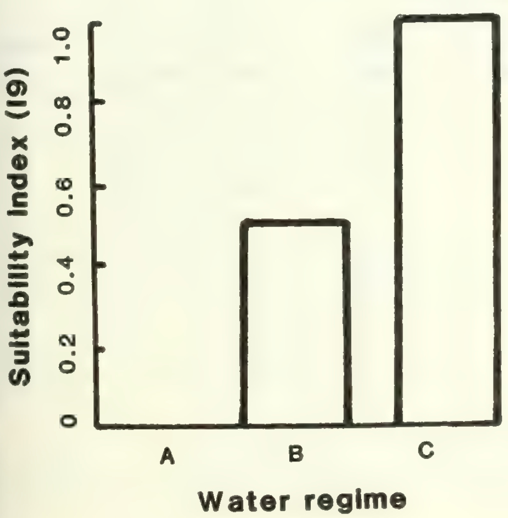
(Figure 7 continued)



Aquatic habitat must be at least 4 ha in size and either a single water body or a group of water bodies each at least 0.1 ha in size and within 0.4 ha of each other.



A - No cover
B - Emergent herbaceous vegetation or downed timber only
C - Herbaceous and woody emergent plants 39-69 cm above the water surface. May also include downed timber.



A - No water or ephemeral flooding
B - Water available at least from mid-January to late September but not permanent
C - Water permanent

Table 1.--*Example illustrating the U.S. Fish and Wildlife Service habitat evaluation method for wood ducks*

I. HABITAT PARAMETERS

No.	Description
I1	No. nest cavities per acre
I2	Ave. DBH cavity trees
I3	Ratio open water to cover
I4	Percent water 7.5 - 45 cm deep
I5	Water current (cm/sec)
I6	Distance to water (km)
I7	Aquatic habitat size (ha)
I8	Cover type
I9	Water permanence

II. FORMULAS

Food Value = $(I3 \times I4)^{0.50}$
Aquatic Value = $(I5 \times I7 \times I9)^{0.33}$
Cover Value = $(I3 \times I8)^{0.50}$
Reproductive Value = $(I1 \times I2 \times I6)$

III. CALCULATIONS

Habitat parameter	Field data	Suitability[1] index
I1	20	1.0
I2	30	0.5
I3	60:40	0.8
I4	60	1.0
I5	0	1.0
I6	0	1.0
I7	4	1.0
I8	C	1.0
I9	C	1.0

[1]From curves in figure 7

Food value = 0.89
Aquatic value = 1.00
Cover value = 0.89
Reproductive value = 0.79

muskrat, and 110 habitat units for beaver, then the wetland would provide a total of 533 wildlife habitat units. Habitat suitability models have been developed by FWS for many wildlife species nad are available in the form of habitat evaluation handbooks (e.g. Flood, *et at.* 1977).

Corps of Engineers Method

The U.S. Army Corps of Engineers (COE) has also developed in recent years a method of classifying fish and wildlife habitats according to relative value. Unlike HEP, the COE method, called Habitat Evaluation System (HES), does not treat individual fish and wildlife species. Rather, habitat characteristics are used that indicate habitat quality for fish and wildlife sources as a whole (U.S. Army Corps of Engin 1980).

Like HEP, HES also determines the quality given habitat type from functional curves relating h itat quality indices (HQI) from the functional cur Each HQI is then assigned a weight, ranging fro to 100, which reflects the relative importance of particular habitat variable in describing overall h itat quality. Weighted scores of key habitat varia are then summed and divided by 100 to yield an gregate HQI. An example showing how the H method would be applied to water-impoundment provided in table 2; the functional curves used in example appear in figure 8.

CONCLUSIONS

Considerable knowledge has been compiled reg ing the relation between biotic and abiotic condit associated with a particular wetland and wildlife of that wetland. Much effort has also been devote developing methodologies that managers can us quantify the relative wildlife value of wetlands. In dition to the two methods discussed in this paper, let (1972) has developed an innovative system

Table 2.--*Example illustrating the U.S. Army Corp Engineers habitat evaluation method*

I. HABITAT PARAMETERS

No.	Description
P1	Mean lake depth (ft)
P2	Turbidity (Jackson Units)
P3	Total dissolved solids (ppm)
P4	Chemical type
P5	Shore development index
P6	Spring flooding index
P7	Fish standing crop (lbs/ac)

II. CALCULATIONS

Habitat parameters	Field data	HQI[1] score	Weight[2]	We
P1	60	0.78	15	
P2	200	0.40	15	
P3	500	0.80	20	
P4	3	0.80	5	
P5	30	0.97	5	
P6	1,000	0.60	20	
P7	200	0.90	10	
			100	

[1]From figure 8.
[2]Assigned by COE

Total Weight HQI = 63.5/100
= 0.64.

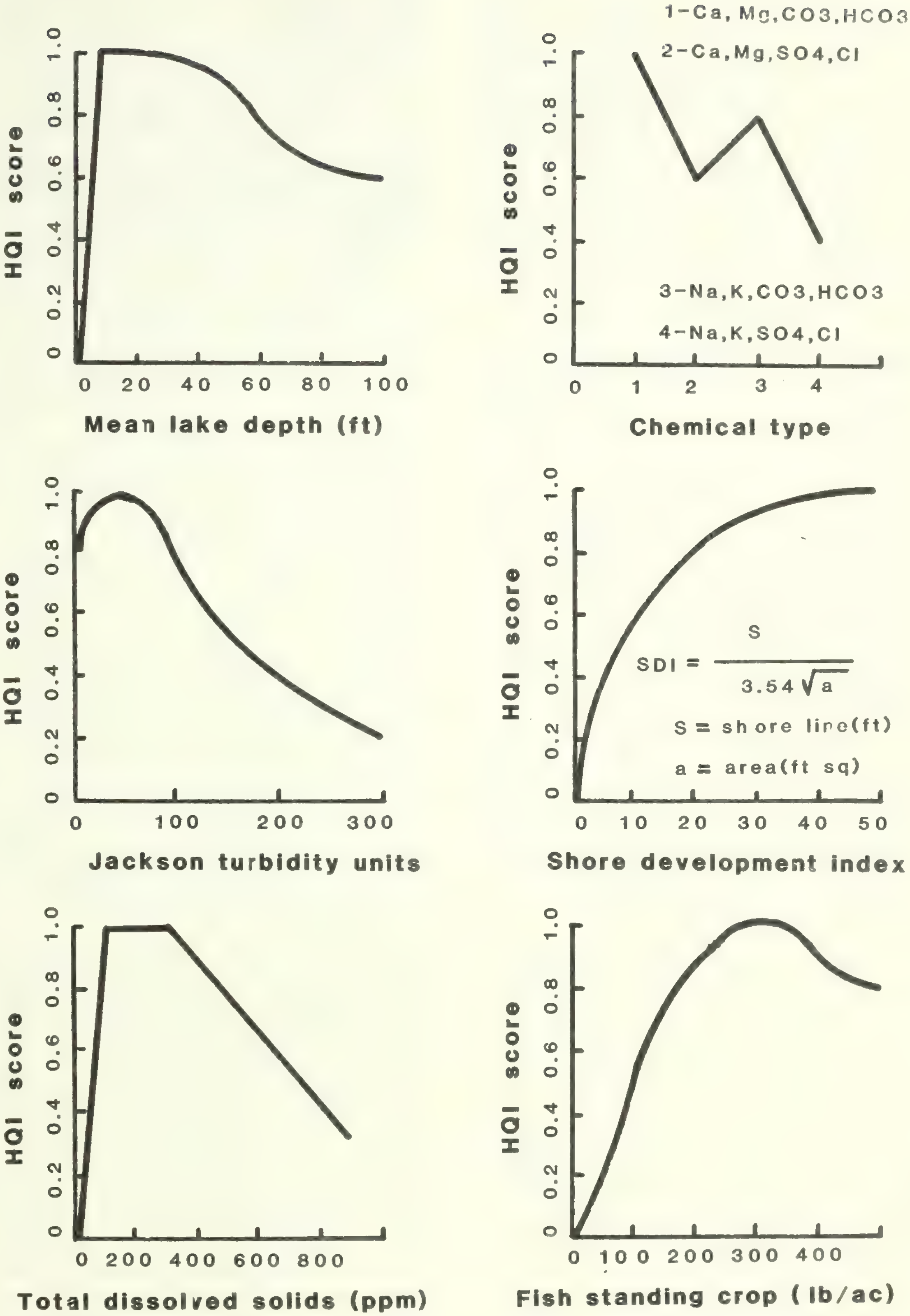
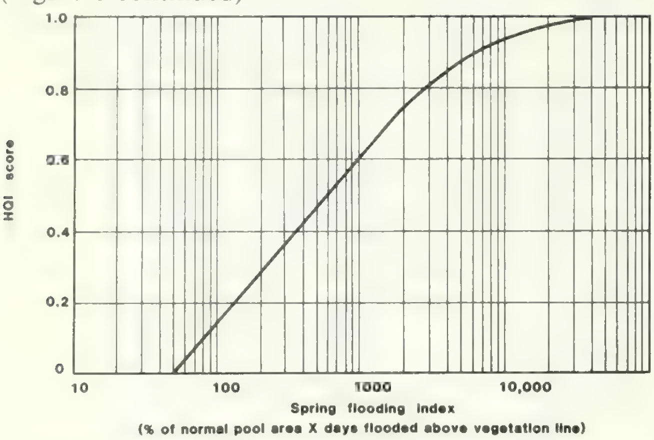


Figure 8.--*Functional curves relating six habitat variables to habitat quality indices (HQI).*

(Figure 8 continued)



classifying wetlands in the northeastern U.S. according to wildlife value. All of these efforts have potential for enhancing the management of artificial impoundments for wildlife. Some important guidelines derived from these works follow.

In order to successfully develop or modify water impoundments to benefit wildlife, the manager must first know which wildlife species the impoundment is to attract. If waterfowl are primary, then water-cover ratio, impoundment age, and water conditions that promote the production of macro-invertebrates (e.g., water chemistry, soil fertility, and water depth) will likely be most important. If on the other hand, wildlife diversity is desired, these factors are less important.

Wildlife diversity is closely associated with habitat diversity. Thus, if possible, impoundments should be constructed as several smaller units rather than one large unit. Such a design would enhance wetland clustering and habitat diversity, thereby promoting maximum wildlife use. Design would also have to be compatible with other social and economic goals associated with the impoundment.

Nearly all species of wildlife have special habitat requirements that must be filled if populations are to achieve maximum levels. Snags, for example, are needed by many species of passerines. These requirements must be identified before development is started so they can be integrated into the overall design.

Finally, and perhaps most importantly, impoundment managers should remember that nearly all of our knowledge related to wetlands and wildlife has been gained through the study of *natural* wetlands. We do not know to what extent this knowledge can be transferred to artificial impoundments. In other words, we have no assurances that constructing impoundments around guidelines developed from the study of natural wetlands will lead to comparable wildlife use on manmade wetlands. Some research has been conducted to determine waterfowl use of artificial potholes in the midwestern U.S. However, until such research is expanded and applied to other wildlife species and types of impoundments, it will be difficult to formulate construction guidelines that will promote wildlife use.

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THE PUBLIC'S USE AND PERCEPTION OF WATER IMPOUNDMENTS FOR WILDLIFE

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Wildlife impoundments or floodings have a long history in Michigan. Water levels in the 850-acre Bentley Marsh in Gladwin County were raised by the improvement of a roadway dike in 1934. Davenport (1959) reported, however, that the first dam construction project took place, also in 1934, at Backus Lake in Roscommon County. The Reedsburg, Dam creating the 2,170-acre Deadstream Flooding in Missaukee and Roscommon Counties was completed in 1940. These few units were the first major wildlife floodings (> 100 acres each) of a list that now encompasses 118 units totaling some 41,300 acres (fig. 1). In addition to these

Figure 1.--*Locations of Michigan's wildlife impoundments of 100 acres or more (118 units constructed, 1934-1982; 41,300 acres.*

major floodings, Michigan has constructed over 450 minor wildlife floodings (< 100 acres each) that total an additional 4,200 acres, mostly in southern Michigan.

The history of development of major wildlife impoundments (100 acres plus) in forested areas of Michigan is shown in the following tabulation:

Years	Number of impoundments	Total acreage
1926-1935	2	1,490
1936-1945	1	2,170
1946-1955	25	12,710
1956-1965	18	7,459
1966-1975	8	5,547
1976-1982	9	1,180

Most of the major forested area floodings were funded and constructed by the Department of Natural Resources Wildlife Division from 1950 through 1974, some 51 units totaling 26,000 acres. Primary funding for these projects was derived from the Pittman-Robertson Fund and the State's Game and Fish Protection Fund. However, a number of recent cooperative projects include substantial, or even primary, funding from the Soil Conservation Service and from the Dignell-Johnson Fund.

The typical Michigan wildlife impoundment in forested areas has been created by construction of a low-head concrete dam with one or more stoplog bays for control of water levels. The dam was usually situated across a creek or river channel that traversed herbaceous meadow or brush or timbered swamp. Frequently the dam was placed at the same site as old beaver dams or logging dams. Earthen dikes of various lengths connect the dam to the nearest high ground and an emergency spillway is typically situated in the dike near the dam. A smaller number of impoundments have been constructed with radial gates in the dams and the most recent impoundment has a fish passage ladder.

Interior improvements were constructed within the shallowest areas of some impoundments by dragline or bulldozer, including level ditches, potholes, and waterfowl nesting islands. Brush and trees were sometimes removed from interior islands or upland edges to enhance waterfowl nesting opportunities. Fluctuation of water levels, primarily drawdowns to re-establish cover plants or food species, has been the major ongoing management technique employed on a periodic basis on these floodings.

The dependability of the water source at each flooding has varied depending upon characteristics of the watershed and the engineering employed. In some cases, it has been difficult to refill impoundments during late summer or early fall after a prolonged drawdown.

Burning of accumulated vegetation or dead timber and some millet seeding, has also been practiced during drawdowns. In the last 10 years, small open meadows have been created along the upland edges of some floodings to provide herbaceous browse to enhance local goose production and migrant goose use. Scheduling of drawdowns and other management improvements has typically been left to the initiative of each local biologist.

Major duties of the Michigan Department as stated by its charter laws are to protect and conserve the State's natural resources, foster and encourage the protection and propagation of game and fish and to provide and develop facilities for outdoor recreation. The past and current program for development and maintenance of wildlife impoundments fits these criteria quite well.

PUBLIC USES OF WILDLIFE IMPOUNDMENTS

Michigan's experiences in wildlife flooding management may not be unique from that of other midwestern States; however, Michigan is a populous State with 9.2 million, mostly urban residents (1980 census). Most major wildlife floodings are within 4 hours' driving time of the State's large urban centers. Michigan residents have been accustomed to traveling for outdoor recreation and the State also hosts many tourists attracted to the outdoor scenery and variety of outdoor recreational opportunities. Tourism, is in fact, the State's number three industry. People, therefore, do have a significant influence on management of the State's wildlife impoundments.

Boss (1976) studied human uses of the Maple River wildlife impoundment in southern Michigan and the Townline Creek impoundment in the north central part of the Lower Peninsula. He determined from postcard questionnaires that the public engaged in a minimum of 16 activities over the 11-month period from March 1974 through January 1975. Most prominent of these activities were hunting, fishing, trapping, birdwatching, and hiking (table 1).

Miscellaneous activities listed included boating, parking, photography, private study, picnicking, and dog exercise. Birdwatching was popular only on the Maple River Flooding which is about 30 miles north of Lansing and adjacent to and in open view of a primary interstate highway.

Belyea and Lerg (1976) reported 35 human activities for southern Michigan waterfowl project areas encom-

Table 1.--*Two Michigan wildlife impoundments March 1974 to January 1975*[1]

Activity	Maple River (Southern Michigan)		Townline Creek (Northern Michigan)	
	Weekday	Weekend	Weekday	Weekend
	man hours/acre/100 sample days			
Bird watching	0.02	0.71	--	--
Boating-canoeing	--	.13	--	--
Bow fish-spearing	.05	.29	--	--
Exercising dog	--	.06	--	--
Fishing, general	.02	.33	0.07	--
Fishing, ice	.04	--	--	--
Hiking	.11	.53	--	--
Hunting, deer	--	.03	.02	--
Hunting, upl. game	--	--	--	0.04
Hunting, waterfowl	1.72	5.29	--	.65
Misc. collecting	.01	--	--	--
Parking	.02	--	--	--
Photography	.02	.08	--	--
Private study	--	.04	--	--
Picnicking	.01	--	--	--
Trapping	.42	.45	--	.02
Total	2.44	7.94	.09	.71

[1]Adapted from Table 13, p. 38 of unpublished M.S. Thesis, Impacts of Permanent Flooding on Two Natural Wetlands in Michigan, 1976, Boss, J. W., Central Michigan University, Mt. Pleasant.

passing the 12-month period of December 1973 through November 1974 (table 2). Hunting constituted 28 percent of the activity hours (mostly waterfowling = 23.9 percent) and non-hunting activities 72 percent. Fishing was the single most important activity--57 percent of all reported activity hours. Camping, boating and boat launching were other significant activities, but nonetheless generated only 10 percent of the activity hours. Overnight camping was prohibited on most of the areas or this activity probably would have been greater.

State Forest campgrounds have been constructed at a considerable number of the northern Michigan wildlife floodings. These campgrounds have been popular sites that have markedly altered the proportion and types of uses on some floodings as compared to the reports by Boss (1976) and Belyea and Lerg (1976).

PUBLIC PERCEPTION OF WILDLIFE IMPOUNDMENTS

In a broad sense activities noted in the studies previously cited reflect the public's perception as to the nature or value of the wildlife impoundments. They also reflect, however, innate characteristics directly related to initial planning: engineering and construction; soils, watershed and water level management; ecological communities and other subsequently imposed physical/cultural developments, such as roads, trails, and campgrounds. Of all activities previously noted, the wildlife impoundment in Michigan is probably most perceived by the public as a fishery resource or a potential fishery resource; this is a State that has 11,000 natural lakes. Secondly, I believe the public perceives them as places to camp, boat, or swim. Thirdly, they are good and interesting places to hunt and trap. Fourth, they are perceived as unique wildlife production areas and places to view unique wildlife including ducks, geese, herons, otters, beavers, ospreys, and eagles. Finally, another group views them as sources of water problems, too much water to upstream residents, or too little water to downstream residents.

These perceptions and those of other special interest groups can be illustrated by examples:

1. Innumerable personal conversations with field biologists reveal that the public has removed or replaced stoplogs on a frequent basis; fishermen, waterfowl hunters, and boaters usually tend to seek increased water levels. Drawdowns seldom seem to be understood by these users or trappers and not at all by campers. Resort owners have attributed decreased pike fishing success in Potagannissing Bay to interruption of spawning runs by the wildlife dam at the Potagannissing Flooding on Drummond Island.

'able 2.--*Recreational activities on southern Michigan vaterfowl areas, December 1, 1973 to November 0,1974*[1]

ctivity	Estimated people hours	Percent
otal non-hunting	931,856	71.9
otal hunting	364,006	28.1
rand total	1,295,862	100.0
ITEMS		
ishing	739,664	57.1
Vaterfowl hunting	309,145	23.9
amping	33,453	2.6
oating and canoeing	29,931	2.3
oat launching	27,671	2.1
arget practice	24,618	1.9
pland game hunting	23,294	1.8
eer hunting (bow & arrow)	15,750	1.2
nowmobiling	11,881	.9
eer hunting (firearm)	10,191	.8
rapping furbearers	9,484	.7
ightseeing	9,471	.7
irdwatching	8,700	.7
icnicking	6,361	.5
quirrel	5,731	.4
iking	4,663	.4
on-hunting undifferentiated	4,523	.3
ut-take pheasant hunting	4,418	.3
re-hunting activity	4,239	.3
ature study	3,544	.3
lushroom picking	2,650	.2
hotography	2,354	.2
wimming	1,844	.1
couting	1,772	.1
og training and exercise	1,594	.1
oafing	1,037	.1
irewood gathering	663	--
lotorcycling	545	--
unbathing	314	--
ndifferentiated hunted	296	--
ox hunting	296	--
erry picking	242	--
ross country skiing	222	--
liscellaneous collecting	219	--
Vater skiing	196	--

[1]Table 2 taken from p. 34, Public Use of Southern Michigan Game and ecreation Areas, 1976, Belyea, G. Y. and J. M. Lerg, Wildlife Division Report 2754, Michigan Department of Natural Resources, Lansing, Michigan.

. In Benzie County, upstream residents attribute death of trees on their property to water levels generated by the Grass Lake wildlife flooding. Hydrologists tell us that holding of design levels should not be causing this problem.

3. In Montmorency County sharply reduced levels in a downstream lake were attributed to the holding back of water in the Rainy River Wildlife Flooding. Hydrological records demonstrate that for the fourth time in this century the subject lake emptied into a subterranian limestone sink hole.
4. In Roscommon County, at the South Pike Marsh flooding, burning to control encroaching brush was ruled out by DNR biologists because of perceived problems with the public including the potential for smoke hazards to traffic on adjacent highways and the deposition of wind transported ash on nearby lake shore homes and yards. Increases in water levels to control brush were also ruled out because increased flooding against roadway embankments was opposed by County and State highway officials.
5. In Alger County, downstream residents expressed concern for guaranteed water releases to protect stream quality below the Sand River Flooding. Marquette County duck hunters, who had secured a portion of the funding to develop the flooding, opposed installation of an osprey nesting platform on the basis that it would interfere with waterfowl hunting activities.
6. In Bay County, the Tobico Impoundment which has been mostly a waterfowl refuge, has been monopolized by visitors from the adjacent Bay City State Park. Parks interpreters have developed an interpretative display, a marsh boardwalk, and an observation tower.
7. In Mescosta County, the Department of Natural Resources obtained flooding easements from private land owners to complement State land ownership within the flood contours of the planned Martiny Lakes Wildlife Flooding. The 1,420-acre flooding was constructed in 1955. In 1961, landowners and County Commissioners brought suit against the DNR to stabilize water levels under Michigan Law when they were faced with a planned drawdown for wildlife enhancement. Subsequently, the State Supreme Court ruled against the State's claim of legal authority to manipulate water levels for wildlife at this site. Since that time, cottages, resorts, beaches, and campgrounds have fluorished. Resort owners now complain about the presence of introduced resident giant Canada geese on their beaches and lawns and some cottage owners allege that wild rice interferes with their boating access to deeper portions of the impoundment.

SOME BASIC QUESTIONS RELATED TO IMPOUNDMENT PROGRAMS

The previous examples may be useful in examining basic questions; i.e., should wildlife impoundments be single purpose of multi-purpose? Can they be single

purpose? The charter of the Michigan Department of Natural Resources is multi-purpose, but does that mean that every project or program must be multi-purpose? The definition of multi-purpose to the wildlife impoundment manager may simply be the production of ducks and geese for waterfowl hunting and the accommodation of waterfowl hunters during the fall season. He or she may even accept or be heartened by secondary furbearer benefits or the utilization of the impoundment by ospreys.

To the summer tourist, however, the occasional glimpse of an elusive brood of ducks may have nowhere near the thrill of a 2-foot pike on the end of a fishing line. Nor will the duck brood or the osprey have the "meaning" that running up the side of a dike with a trail bike does or toasting marshmallows around the fire at the camping site on the hill overlooking the impoundment. Whose definition of purpose shall be used, that of the wildlife biologist or impoundment user? The impoundment user, depending on background, may not be impressed that hunters' monies paid for construction. If the impoundment resource is on public land with public access, attempts will be made by the general public to use that resource. Since the public's perception of permissible wildlife impoundment uses may vary considerably from that of the manager, public uses must be carefully planned for and guided.

IMPOUNDMENT MANAGEMENT CONCEPTS

An impoundment program must be guided from early on by a set of goals and objectives that includes acceptable public uses and has established the degree to which public utilization can be permitted without seriously jeopardizing the intended functions of the impoundment. It is imperative that the public understand that the management of a productive wildlife flooding is contingent upon uneven water levels, and in fact, little or no water during planned drawdowns. It seems likely that this concept can only be conveyed by a continuous program of public information, starting perhaps with information meetings prior to construction, posting of explicit information signs at access sites, provision of explicit brochures on site and at general locations, periodic news media releases, and of course, actual fluctuation of water levels for specific management purposes. An agency must first however, have a vigorous inhouse program of similar information to make sure that impoundment management concepts and goals are understood, accepted, and properly conveyed to the public. For example, it would be confusing for the public to receive one message from the wildlife biologist, another from the fish biologist, and yet another from the forest campground supervisor.

VISITOR USE AT IMPOUNDMENTS

If the objective(s) for wildlife impoundments include an increase in visitor use, then there are many techniques that can be employed.

First, of course, is to manage the flooding to create those wetland communities that produce a diversity of species and adequate quantities of wildlife to be readily visible.

Second, there is a need for the public to be aware of the location of the impoundments. In a general sense this can be accomplished by providing a comprehensive brochure listing locations, facilities, possible activities, and species of interest. Good driveable roads or trails into impoundments, well-marked with directional signs, will ensure increased visitor use as well as improved parking and boat launch facilities. Impoundments deep enough to support game fish and desirable pan fish species will attract many visitors. Other improvements to be considered include hiking trails, observation towers, wildlife openings, introduction of unique species (e.g.) geese and swans, campgrounds, and even visitor centers, beaches, liveries, and concessions.

It should be obvious that a number of these techniques offer the potential for substantial conflict with traditional wildlife management goals. In particular, these are the physical improvements including the campgrounds, visitor centers, beaches, liveries, concessions, and improved roads. In the proper place, and with proper planning, however, even these facilities may serve a useful purpose. For example, the visitor center at Seney Refuge in Michigan's Upper Peninsula offers an educational message for thousands of tourists each summer about wildlife biology and the need for providing and maintaining wetlands wildlife habitat. Yet it only takes up a small space in a large complex of wildlife impoundments. Perhaps a disadvantage is that resident Canada geese "freeload" on handouts offered by people.

A stormwater, runoff wildlife impoundment in the midst of a well-spaced governmental office complex 8 miles south of Lansing, Michigan (on former farm land) does an excellent job of producing ducks and geese. While the wildlife are exposed to the daily comings and goings of several thousand workers and their auto traffic, natural overlooks permit people to see the marsh without having to intrude into the area. The initial preservation of nesting cover around the marsh by a joint agency management plan was the other ingredient that produced the desired result.

Elsewhere, only a minimally-maintained forest road nay be necessary to provide for hunters, trappers, and nanagement personnel when an impoundment is far ff the "beaten path," and expenditures of funds to mprove visitor use would yield minimum results.

Each agency must decide what public uses are consistent with the primary objectives of their wildlife mpoundments. Then, with a combination of: 1) skillful planning, (2) adequate funding, (3) proper ositioning of physical facilities, (4) selection of appropriate area rules (including time and space considrations), (5) vigorous rule enforcement, and 6) continuing provision of information for the public, ven complex and multi-purpose objectives can be met. The challenge to the agency and the manager is to nesh and carry out these considerations with such fficiency that both people and wildlife will benefit.

DESIGN AND LOCATION OF WATER IMPOUNDMENT STRUCTURES

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Since 1964, when the Chippewa National Forest began constructing wildlife impoundments, about 50 have been completed. We've been learning as we've gone along--sometimes rather painfully. Often, at the start of this program, as soon as an apparently suitable site had been located, we began surveying. Some surveys were completed, and some wildlife impoundments were designed before we discovered that, for some reason, the sites were unsuitable. We even have one of two "skeletons" in our closet--dams that probably should never have been built.

It is very important that a potential impoundment site be thoroughly studied and evaluated to determine whether or not it is practical and economically feasible. This takes place during a preliminary review, followed by a preliminary survey and design process. Work on sites that survive this evaluation is carried forward to final design and construction.

PRELIMINARY REVIEW

Preliminary review involves the study of available maps, photos, and other documents. Most of the review is done in the office, followed by a brief field investigation. At this point, many sites are eliminated, either because of the lack of drainage area, a poor location for the dam, right-of-way problems, or the high cost of construction.

Several tools that are available to assist in evaluating a site are:

1. U.S.G.S. Topographic Maps
2. Aerial Photos
3. Land Status Maps.

U.S.G.S. Topographic Quadrangle maps show contours with which to delineate and calculate the size of a drainage area. The ratio of drainage area to flooded area is important. A drainage area that is small in relation to the flooded area will result in runoff insufficient to fill the reservoir. A large drainage area, on the other hand, can result in a large and costly structure. Ideally, the ratio should be between 10 and 30; however, other factors--such as subsurface flow--must be considered. If U.S.G.S. maps can be obtained in orthophoto (an aerial photo overlay in color on the map), they will be easier to use. Vegetation types and wetlands are shown on orthophoto maps.

Aerial photos of National Forests, taken periodically in the past, usually show the extent of past flooding by beavers, and give a good indication of reservoir size. No better assurance of site suitability exists than the knowledge that it has been flooded in the past.

While low-level aerial photos are valuable tools in evaluating a site, they later on become even more valuable to the survey crew and designers. These photos should be taken in the spring when the leaves are coming out, so they will show the best contrast between vegetation types.

To determine whether private lands will be affected, land status must be checked; then private landowners must be contacted to see if they are willing to grant an easement. If they refuse, a decision must be made to either pursue condemnation or drop the site.

The purpose of the brief field investigation is to obtain more specific information and to get a "feel" for the site. The engineer will be most interested in checking the dam site to determine whether there is sufficient elevation on the sides, what length of dam is needed, and whether marsh excavation will be required. Often the field investigation will reveal that to proceed is entirely impractical. Other items checked in the field are access roads, borrow pit sites, and emergency spillway locations.

PRELIMINARY SURVEY AND DESIGN

After preliminary review, the next step is preliminary (limited) survey and design. If well planned, the field work can usually be completed in one day by a two-man crew.

During the field investigation, the engineer usually puts up flagging to indicate where he wants the crew

survey. Low-level aerial photos, when available, can used very effectively to indicate where surveying iould be done. A clear, acetate photo overlay can be sed to show a proposed dam site, borrow pit, survey nes, etc. By cutting a line across a proposed dam site, ie crew can measure distances, take centerline ele-itions and check for depth of marsh excavation along ie centerline. They can also measure and take ele-itions along a line extending from the dam upstream the end of the area proposed for flooding.

The engineer, by plotting and analyzing the field ita, can determine within a short time whether a site suitable and the approximate cost of constructing ie impoundment.

It is very important to examine the levels taken ong the line which extends upstream from the dam. 'hen elevations change, either too gradually or too ipidly, the effectiveness of an impoundment is re-iced. The ideal pool depth for waterfowl is 12 to 30 ches. The ideal pool elevation is one that produces ie maximum size pool within this depth range.

When elevations change too gradually, it is possible iat too much area--including timber, private lands, id water bodies--would be affected.

When elevations change too rapidly, it is possible iat any given pool elevation would flood only a rel-ively small area to a suitable depth.

Plotting of the dam centerline survey will give in-rmation relating to earthwork volumes, structure ze, and other features.

The preliminary survey and design will provide the llowing information:

1. Approximate size of reservoir
2. Size and type of structure
3. Layout of the dam
4. Costs within 10 percent accuracy.

Preliminary survey and design should provide suf-ient information to determine whether or not a site worth developing. If a decision to proceed is made, e final survey and design will be done.

FINAL SURVEY AND DESIGN

Except that they are more detailed and extensive, e final survey and design don't differ much from the eliminary one. Exact reservoir boundaries are de-rmined and elevations are taken throughout the pro-osed reservoir to determine flooding depths. A etailed survey with soundings is made at the dam site accurately determine excavation and borrow quan-ties.

The final design is made with the following in mind:

1. Low construction cost
2. Ease of maintenance and operation
3. Visual attractiveness.

Normal Pool

After elevations have been plotted and contour lines drawn, the normal pool elevation is selected. The area enclosed by each contour line is calculated, allowing the wildlife biologist to select the elevation that will produce the maximum area flooded to proper depth (table 1). Elevations at the sides of the dam and around the reservoir often control the maximum allowable pool elevation.

The height of the dam, elevation of the emergency spillway, and--to a certain extent--the size and type of control structure, depend greatly on selection of the normal pools.

Table 1.--*Sample calculation for determining normal pool elevation*

		Flooding depth (in feet)			
Contour		Normal pool elevation			
interval	Acres	108	109	110	111
103 - 104	1	4-5	5-6	6-7	7-8
104 - 105	3	3-4	4-5	5-6	6-7
105 - 106	6	2-3	3-4	4-5	5-6
106 - 107	8	1-2	2-3	3-4	4-5
107 - 108	16	0-1	1-2	2-3	3-4
108 - 109	14		0-1	1-2	2-3
109 - 110	7			0-1	1-2
110 - 111	7				0-1

To determine the area flooded to certain depths under various normal pool elevations, enclose the desired range of depths between parallel lines. Then add the acreages flooded for each of the corresponding contour intervals.

Example--Area flooded to 1-3 foot depth

Elevation	Area
108	14 acres
109	24 acres
110	30 acres
111	21 acres

A normal pool elevation of 110 will give the most area flooded to a 1 to 3 foot depth.

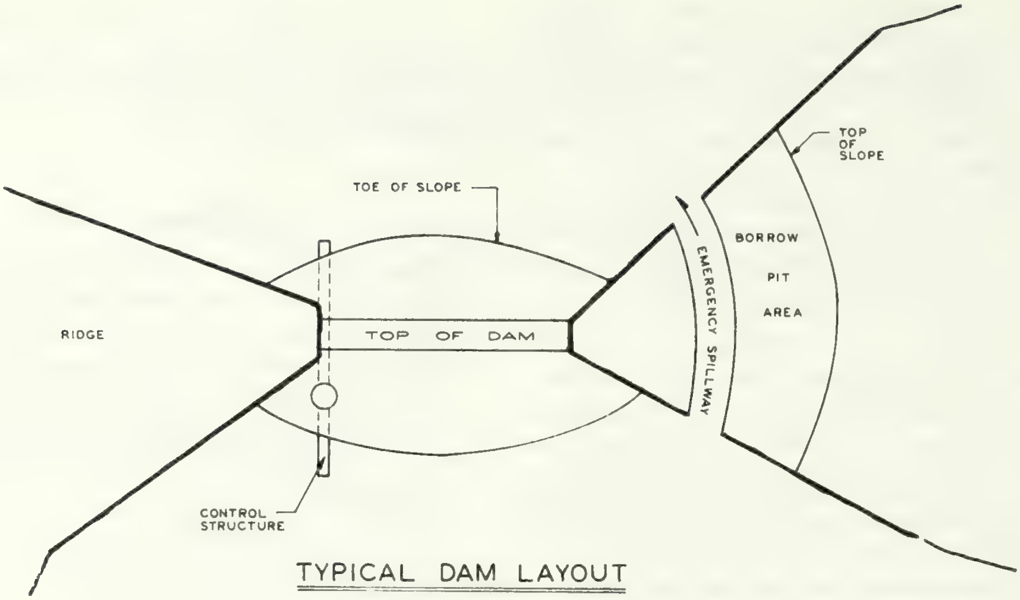

Figure 1.--*Typical dam showing borrow pit and emergency spillway.*

Dam

Unless other factors such as marsh excavation govern, the dam is usually located at the narrowest gap in the flowage. Generally, the best layout is to have the borrow pit next to the dam, with the emergency spillway constructed as part of the borrow pit (fig. 1). Basically, the designer attempts to use as little material as possible and to move it the shortest possible distance.

The design of a dam is governed by the type of material used. To prevent seepage, dams constructed out of sand need flatter slopes than those constructed of clay.

Unless it is to be used as a roadway, the top of a dam is generally 10 feet wide. Because it is difficult to modify a dam for traffic at a later date (by widening and graveling the top), it is very important to know in advance whether a dam will be used as a roadway.

An emergency spillway is used to protect the dam. Generally, the crest elevation is about two to three feet below the top of the dam. Sometimes, with minor modifications, a natural drainage can be used as an emergency spillway.

Water Control Structure

There are two types of water control structures--the whistle tube and the drop inlet (fig. 2). Probably the most common, the whistle tube comes prefabricated in a variety of sizes and is easy to install and maintain. There are several variations of drop inlet construction. It can simply consist of a half-round culvert pipe with a stop-log channel on the front side, or be of concrete construction. Often a tossup, the decision of whether to use a whistle tube or drop inlet is up to the designer or operator.

To reduce the risk of settlement, the structure should not lie on fill material or where a marsh has

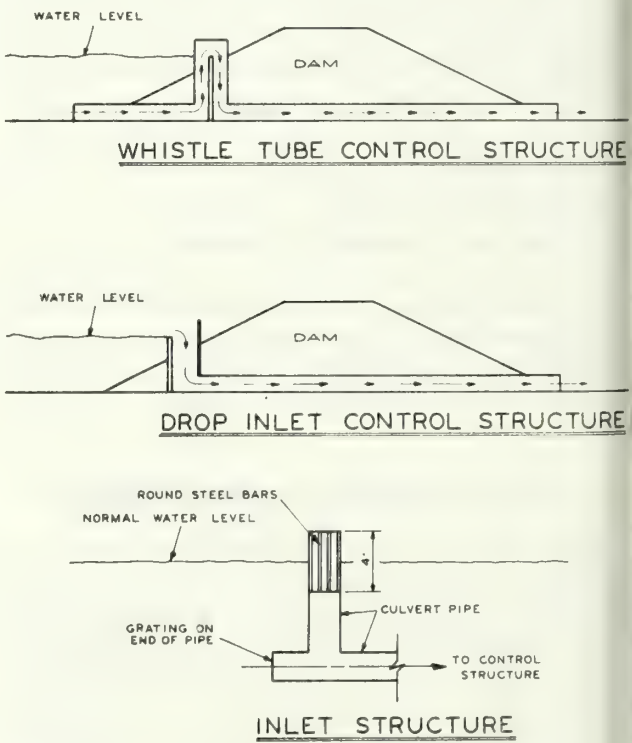

Figure 2.--*Typical water-level control structures.*

een. Often the best location is near the ends of the am, where the ground is the most solid.

To prevent any leakage from following along the pe and washing out material, the outlet pipe will ave anti-seep diaphragms, and the end of the outlet pe should be protected with rip-rap.

Proper construction techniques are essential for in- alling a structure. The bed must be well compacted proper grade, with the fill compacted in layers ound the structure.

Other types of water control structures are possible, d the designer can be imaginative. Two impound- ents on the Chippewa National Forest have been nstructed in conjunction with existing bridges. Us- g sheet piling, each was constructed with the entire ructure serving as a spillway. These structures will ass large flows of water. In one case, an old bridge as removed and replaced with a timber box culvert. he bottom of the box culvert was set at the desired ool elevation, with a structure installed to drain the npoundment.

Inlet Structures

In an attempt to reduce beaver plugging, several inlet structures have been used with the whistle tube. These have met with limited success. The first design, simply an extension of the inlet pipe, was fitted with a grate on the top and at the end. Because they were often submerged under several feet of water, these became plugged easily and were difficult to clean. Later designs have consisted of vertical inlet structures made of wood or metal. Although they also get plugged, they are easier to clean because they are accessible.

Fish Ladders

Two fish ladders to accommodate northern pike migration have been constructed; one of steel sheet piling, and the other of treated timber. Water velocities were kept low, but for some unknown reason, these were not successful. Northern pike seem reluctant to use them, even though they often jump to get over other obstacles.

SO YOU WANT TO BUILD A WATER IMPOUNDMENT

Robert E. Farmes, *Region I Wildlife Supervisor, Minnesota Department of Natural Resources, Bemidji, Minnesota*

The development of an impoundment requires careful planning and strong personal commitment in order to get the job done. I will review some of the necessary steps one must take and discuss some of the problems and considerations involved in the development of a typical impoundment.

RESPONSIBILITY

The first step is assigning responsibility to the proper individual. This individual should possess a thorough understanding of aquatic biology and wildlife management, have a working knowledge of construction methods and equipment, be familiar with the various types of water control structures, and be able to work with all kinds of people under stressful situations. Above all, the person should have established a track record of getting the job done--in other words a doer as well as a good thinker. At the same time he or she must also be able to delegate work and know when consultation with professionals in other disciplines is desirable. Constant and direct communication between the project supervisor and others involved in the planning and design is of utmost importance.

SITING

The site for an impoundment designed to provide waterfowl and other wildlife habitat should have certain characteristics to make a good impoundment. An adequate water supply is most important, so make sure the watershed is large enough to supply these needs. The actual watershed size needed will vary considerably depending on several factors, so it is best to consult a hydrologist about this aspect of site selection.

Make sure the topography of the basin is relatively flat and shallow. Be careful not to select areas that are too flat where water depths will be mostly less than 18 inches. Water too shallow will often result in an impoundment that is overgrown with emergents, providing little open water. Narrowleaf cattail and hybrids of narrowleaf will persist and thrive in water deeper than 18 inches. Water depths of 18 o 48 inches throughout the impoundment will usually result in a desirable ratio of 50-50 open water and emergents. Potential impoundment sites can frequently be determined by observing areas which flood naturally during times of heavy run-off. Aerial observations followed up by ground reconnaissance during spring run-off will often give a person some ideas for potential sites. Photos of these naturally flooded sites will be of value during the planning stages, and U.S. Geological Survey quadrangles can be most helpful during feasibility studies.

Soils are an important consideration in site selection. Generally those areas with the more fertile soil types provide conditions for preferred growths of aquatic vegetation and invertebrates. Poor soils should be avoided unless the water source provides additional nutrients.

Floating bogs are a special problem. In some areas that are impounded the vegetative mat simply lifts up, forming a floating bog. If no open water remains, little has been accomplished. In other cases only portions of the vegetation will lift forming a good interspersion of cover, islands, and open water. A "Cookie Cutter," a machine that will cut up the floating bog and provide the open water, is useful in some of these situations.

Whenever an impoundment is built, certain species of wildlife will be replaced by others. Make sure the trade-off is desirable and the gains will be greater than the losses.

FEASIBILITY SURVEY

If there remains any question about the site, you should request an engineering feasibility survey. This request might include topographic or hydrological information or a preliminary cost estimate. Final plans and specifications should not be requested until you are relatively sure the project is feasible from a cost, construction, and land control standpoint.

LAND OWNERSHIP

Surprisingly, land ownership is often overlooked even though it may seem obvious that land control is

ecessary. Time and money may be spent planning a roject only to find out the impoundment will affect ınd that you cannot buy or obtain a flowage easement n. This aspect of planning should be determined as oon as possible and no later than at the time of the easibility survey.

PERMITS

Permits are usually required by State agencies reglating surface waters. Usually permit applications all for specific information, so plans and specificaons need to be submitted along with the application. is recommended that these applications be made as oon as the project is determined to be feasible and hen plans and specifications can be provided.

The Department of Natural Resources, Division of Vaters, administers the permit process in Minnesota. ermits are required when (1) lakes; (2) natural water ourses with a watershed over 2 square miles; or (3) etland types III, IV, and V (USF&WS Circ. 39) over 0 acres (2½) acres in municipalities) are affected. Aplications are made to the regional hydrologist.

The Dam Safety section in the Division of Waters lso reviews plans to assure that construction meets am safety requirements.

In addition, the Pollution Control Agency and the tate Archeologist review permit applications in Minesota. The State Archeologist will often require an rcheologicl survey prior to construction. All persons, orporations, and governmental units are required to ave permits.

Another permit may also be required if legal drainge systems are affected. Applications in these cases hould be submitted to the ditch authority which may e the County Board, the Watershed District, or the istrict Court depending on the kind of ditch system volved.

In Wisconsin, the Department of Natural Resources egulates the permit system for dam construction and egulates and controls the level and flow of water in l navigable waters. Navigable waters in Wisconsin re defined as: Any stream capable of using a recreional craft for any purpose on a regular recurring asis. The DNR also determines methods of construcon, operation, and maintenance for any dam. Permits ay be issued to any person, firm, corporation or mucipality. Applications setting forth details of conruction are submitted to the Department District Vater Management Coordinator along with a basic $10 fee, plus supplemental fees depending on project value. Federal agencies are exempt from State permit requirements, but State and other units of government are not exempt.

Michigan has several laws affecting dam construction. One or all of the following may apply to any particular project:

1. Dam Construction Approval Act of 1963
2. Inland Lakes and Streams Act of 1972
3. Inland Lake Level Act of 1961
4. Passage of Fish Over Dams Act of 1979
5. Goemare-Anderson Wetland Protection Act of 1979
6. Soil Erosion and Sedimentation Act of 1972

All but the last are administered by the Michigan Department of Natural Resources. A permit consolidation process now allows one application to cover the first five acts. Applications are to be sent to the Land Resource Programs Division at Lansing.

Applications must include plans and specifications prepared by a registered engineer. Michigan charges a fee ranging from $200 to $600 depending on the size of the project. Everyone must go through the permit process, but fees are waived for State and federal agencies. All applications go through a public notice procedure.

The Soil Erosion and Sedimentation Act is administered by county and township boards. Apparently all impoundments come under the provisions of this act. In general this act requires that proper erosion and sedimentation practices be incorporated into the construction, operating, and maintenance plans.

In addition to a State permit, a federal permit has been required for most impoundment construction in the past. The U.S. Army Corps of Engineers regulates the discharge of dredged or fill material into the waters of the United States through Section 404 of the Federal Water Pollution Control Act of 1972. Generally a federal permit has been required if wetlands or other bodies of water over 10 acres in size were affected by fill or dredged material. However, recent changes have been approved by the Office of Management and Budget which removes the 10 acre limit and now all "isolated" waters will come under a nationwide permit. This means individual permits are not required in States where nationwide permits have been approved and anyone may place fill or dredged material in these so called isolated waters without a federal permit.

PREPARING PLANS AND SPECIFICATIONS

The supervisor in charge of the project may or may not be involved in the details of construction design depending on his/her particular experience and whether or not an engineering staff with design experience is readily available. As a minimum the project supervisor should have an opportunity to review plans and specifications. Since elevations and drawdown capability are extremely important, this aspect of design should be reviewed very carefully. Make sure structures are designed to accommodate the highest normal pool elevations you believe will ever be desired. Water elevations can always be lowered, but once the structures are built, higher elevations are impractical without additional construction. When reviewing the plans and specifications *do not take anything for granted.*

The dike elevation should be three feet above maximum normal pool elevation allowing for one foot of bounce and two feet of freeboard during flooding. Dike top width and side slopes can vary somewhat depending on head of water, dike materials, and budget considerations. On small impoundments a minimum top width should be eight feet and side slopes 3:1; larger projects should have a 12 to 15 foot top and at least 4:1 side slopes.

Water control structures should be designed to allow a maximum of one foot of bounce over normal pool elevations. All structures should be designed so that heavy equipment can readily travel the dike for maintenance and emergency repairs. The principal structure should be designed to allow for water level manipulation as well as complete drawdown.

Projects with large watersheds usually incorporate emergency spillways into the design in order to handle periods of heavy run-off. These should become operational when one foot above normal pool is reached. Emergency spillways are designed to release floodwaters that are surplus to what the principal structure is designed to take. These may be simply a low spot in the dike heavily rip-rapped with field rock, or in cases where erosion is a problem, steel sheet piling may be driven down the center of the heavily riprapped area. In extreme cases, concrete spillways may be needed to prevent erosion and failure of the spillway.

CONSTRUCTION

The question of whether to do the work by private contractor or with your own crew and equipment is usually determined by budgets, equipment, and personnel available. When given a choice, I prefer the private contractor. Cost comparisons show that on the larger projects contractors will often do the job for less than with your own work force and you will not have a lot of your labor force tied up on one project.

If the work is done by private contractor it is advisable for the project supervisor to call a pre-construction conference between the contractor, the engineer, and any others involved in the planning and design of the impoundment so that everyone understands what the plans call for.

Agencies must usually obtain bids if the project is done by contract. Bids may be called for in a number of ways. The project may be bid in one lump sum, but if this is done a very complete set of plans and specifications needs to be furnished to potential bidders. Often it is an advantage to separate out the earth work form the control structures because many contractors have expertise in only one or the other or these areas. In this way you will obtain more bids and likely get the job done at less cost.

If you ask for separate bids on the earth work, it may be bid in one lump sum, by the cubic yard, or by the hour. If bid by the hour you must furnish good specifications on the equipment you wish to rent. Usually crawler tractors with scrapers, crawlers with dozers, draglines, or a combination of these are used. *Generally the larger equipment will do the job at less total cost.* Crawler tractors should have power shift with a minimum of 200 flywheel horsepower (D8H-46A or larger). Draglines should have at least a full one yard rating and carry 60 feet of boom. In some cases some of the larger backhoes may be able to replace the dragline. If large amounts of dirt are to be moved by dragline a larger machine in the 2 to 3 yard capacity carrying 80 to 100 feet of boom should be considered (American 700 series or equivalent).

All machines should be equipped with a Servus Recorder (an instrument that records on a paper disk when the machine is operating) when doing hourly work. Payment is based only on the hours recorded. Two things are vitally important when doing hourly work: (1) The machine must fully meet specifications called for and be in good operating condition and, (2) The operator must be fully qualified at operating the machine under similar conditions. It is best to specify that the operator have a certain minimum hours operating the equipment. If the bid is made in a lump sum amount or by the cubic yard, some of the above is not nearly as important.

How do we determine what equipment should be used for the earthwork? When bidding is by the cubic yard or in a lump sum this will be determined by the contractor. If the work is hourly this aspect needs to

determined before calling for bids. Dozers, dozers th scrapers, and then draglines should be used in at order if soil and moisture conditions permit. Doz-s will often move dirt for half the cost of a dragline nile dozers with scrapers are somewhere in between, pending on how far the dirt is to be moved. Under t, heavy soil conditions draglines with mats are usu-y needed. In some cases low ground pressure (LGP) awlers can operate; they should be considered unless e area is extremely wet.

Dike construction techniques are important and ould be thoroughly understood by the project su-rvisor. Construction methods will depend, to some ent, on soils at or near the site and the type of uipment used. It is less costly to obtain fill material mediately adjacent to the dike, and it is best to rrow this material from the outside, but if necessary is permissible to borrow from the pool side. The nter of the dike should consist of impervious ma-ial to prevent excessive seepage. Where no imper-us material is available, a diaphragm embankment y have to be considered as an alternative. Dia-ragm embankments are those which incorporate a -off wall through the middle of the dike to form a ter barrier. Usually steel or wood sheet piling is ven down to an impervious foundation. Another al-native is to line the pool side with a clay blanket a t or more thick. Both of these alternatives are ex-mely costly techniques that are recommended only areas where other methods to prevent seepage are practical, and where the expected benefits to wild- are much higher than average. All organic material d debris should be removed from the base of the e before fill is excavated and in areas of deep peat ore should be constructed. The core trench is ex-ated to mineral soil and then back filled with clay. he dike is constructed with dragline, a berm of at st 15 feet should be left between the toe of the dike d the near edge of the borrow pit.

Fill cast up by a dragline should be about 25 to 30 cent greater than required to allow for settling. Ma-ial from dragline constructed dikes is usually quite t and if much clay is involved a year or more may needed before leveling by dozers can be done. Com-cting successive lifts with dragline-constructed es is usually not practical because of the wet ma-ial. However, unless dike failure would result in loss ife or valuable property, it should not be necessary meet rigid compaction standards under low head uations. Beefing up the dike may be a cheaper way treating anticipated seepage problems where see-ge may cause dike failure. Final leveling and shaping uld be done with a medium-sized motor grader. The e top should have a slight crown to allow water to n off.

Dike side slopes should be dressed with 2 to 3 inches of organic material to provide a seed bed. Seeding the dike should be done to prevent erosion and to provide food and cover for wildlife. Where dikes are several miles long they can provide an important source of highly nutritious food for a large variety of wildlife. Dikes seeded to a mixture of 2 pounds Parks blue grass to 6 pounds White Dutch clover with oats as a nurse crop and fertilized have been heavily utilized in Minnesota by deer, sharp-tailed grouse, Canada geese, and mallards. Since dikes provide excellent travel lanes for many predators, avoid seeding dikes to nesting cover where ground predators may be a problem. Vegetation with deep tap roots should be avoided as these tend to weaken the dike when the roots die. It usually pays to fertilize with 100 to 200 pounds to the acre with a formula recommended for the soils in the area. When vehicles need to travel the dike frequently, it is advisable to gravel the top, but graveling should be done only in the late fall or winter after the dike has frozen sufficiently. This is especially important on new dikes that are still comparatively soft.

COST CUTTING IDEAS

Most agencies are currently working under tight budgets, but still we should always be looking for ways to get the most out of our wildlife dollars. Here are some ways to stretch the dollar.

Engineering studies can use a large percentage of your construction money. Although highly detailed plans and specifications are necessary and desirable in some cases, they are not always needed. One of the easiest ways to save on engineering costs is to obtain information on areas that flood naturally by viewing them during spring run-off and during periods of heavy precipitation. You may avoid costly topographic work by securing this kind of information. You should plot the extent of flooding and depths over the area.

Large, elaborate water control structures are expensive. You may want to reduce the size of the control structure and provide an emergency spillway that is utilized with greater frequency.

The impoundment can be built in stages if your budget will not allow immediate completion. The principal water control structure may be temporarily eliminated by using the emergency spillway for all run-off. The principal structure can then be installed when funds become available.

If the work is done by contract you can often save considerable money by doing the earthwork by renting equipment with operator by the hour. When working by the hour contractors do not need to build in the

insurance they do when they bid a total price on the job. You also can avoid considerable engineering costs by doing hourly work. The contractor does not need to know, except in very general terms, the cubic yardage to be moved. However, if you decide to bid the earthwork by the hour, you must make sure the contractor has good equipment and will provide a competent operator.

Dam safety engineers will usually require that dikes be built so that a high degree of compaction is obtained. This requires costly construction methods involving soil moisture control and adding material in successive lifts. This type of construction may result in costs 50 percent or more above construction without special compaction. This aspect of construction should be evaluated to see if it is really necessary.

The bidding process is another area where costs may be shaved. Bid invitations should be prepared so that a maximum number of qualified bidders are eligible to bid. Calling for very specialized equipment will usually result in few bids at higher costs. Make sure the job is well advertised. Smaller contractors with fewer overhead costs usually are able to bid jobs lower than the large companies, so make sure your bid bond and other requirements do not rule these out.

Actual construction costs per developed acre can vary considerably. At today's prices most impoundments will run from $200 to $300 per acre. Anything over $500 per acre should be looked at critically to see if there are alternative sites where costs might be lower. If development costs are more than it would cost to buy natural marshes in the area, perhaps the money would be better spent acquiring natural marshes.

From initiation to completion, the planning and construction of an impoundment can be very lengthy. In extreme cases, you may wait several years before all hurdles are cleared. Most, however, are completed within 2 to 3 years. Take one step at a time and don't become discouraged by the bureaucratic processes. If you have a good site, and you have planned properly and have pushed and shoved when needed, you'll get the job done.

SUMMARY AND RESEARCH NEEDS

Lewis M. Cowardin, *Wildlife Biologist, Northern Prairie Wildlife Research Center, Jamestown, North Dakota,*
and **W. Reid Goforth,** *Program Manager, North Central Forest Experiment Station, Grand Rapids, Minnesota*

The purpose of this workshop was to update infor- ation on water impoundments for wildlife and based this information to prepare a symposium proceed- gs that will assist managers faced with decisions on ay, where, and how to build impoundments, and how manage them. We will highlight the various papers esented and assess, from our point of view, where e purpose of the workshop was accomplished and iere important questions remain unanswered. These answered questions form the basis and justification r additional research.

Impoundments are one type of wetland and prob- ns in impoundment ecology can only be understood the more general context of wetland ecology. Leigh edrickson set the stage by giving a rapid review of e variation and complexity of wetland ecosystems. e pointed out that they are curcial to the well being a number of furbearers, birds, herptiles, and fish. ie requirements of these animals for wetland habitat ay be short in time but critical to their life cycle. iere is still a need for more details of life history formation for many species that utilize these im- undments. It is critical for the manager to know iich limiting factors are being supplied to the various ecies that use his impoundments.

Wetland habitats are in jeopardy because of destruc- n and modification by man and impoundments can used to mitigate this loss. To function effectively, poundments must, to some extent, duplicate the tural system that they are to replace. This can only accomplished by understanding function and dy- mics of wetland systems. Unfortunately, though ich is known, much remains to be learned. In many ses, adequate research tools have not been devel- ed. We need research that will provide information how to better predict productivity as part of the e selection process. We also need better information the subtleties of the impoundment degradation ocess.

Robert Radtke showed the immediacy of the problem of wetland loss mentioned by Leigh. Because of the high loss of wetlands in agricultural regions of the prairies, wetlands in forested areas will assume a new significance in the battle by federal, State, and local governments and private groups to stem the loss of wetlands. The prospects for achieving stated preservation goals are not bright. If the fight to preserve wetlands is to be won, better coordination among agencies will be essential. Lowell Suring showed that the effort to preserve wetlands is by no means a recent development. The problem of wetland loss was recognized in the 1930's and at that time drained marshes were reclaimed for wildlife. He then traced the history of impoundment development to the present.

The remaining papers were much more specific in nature. They dealt with impoundments in the forested northern Lake States. John Mathisen addresed the difficult question of why we need impoundments on an area like the Chippewa National Forest that has abundant natural wetlands. Drawing on wildlife use data, later illustrated by Donald Rakstad, he assessed whether impoundments meet their objectives. He concluded that impoundments fill wildlife needs that are met by the least common wetland types; therefore, conversion of shrub swamps, sedge meadows to impoundments that simulate seasonal or semipermanent wetland types help meet wildlife management objectives. His assessment was based on a logical procedure where he quantified wildlife value of habitat based on the number of species present and developed a simple method for comparing areas. Gary Williams illustrated another simple method of evaluating habitat, again based on species richness but using different attributes than those used by Mathisen. We still need research to answer questions about values of species richness vs. numbers of individuals of particular species. We cannot assume that an impoundment use by many species is always best. We also need to know if

we see increased use patterns at impoundments because we are helping increase population levels or because we are simply attracting animals from other areas.

With the question of why build impoundments resolved, the remaining papers moved to the question of where and how to build and manage them. Sandy Verry reviewed studies of water quality and illustrated the implications of impounding water on temperature, coliform bacteria, pH and nutrients. He made the perhaps heretical statement that drawdowns do not recycle large quantities of nutrients. The nutrients are released from bottom muds under the ice regardless of water sources or timing of drawdowns. What, then, are the advantages of drawdowns? Dean Knighton presented data showing that drawdowns can be used to obtain the interspersion among life forms of vegetation that John Mathisen had shown to be important for obtaining diversity of wildlife species. Additional research is needed in this area.

Fred Reid discussed the importance of drawdowns on invertebrates that form the food source for many species of wetland wildlife. He pointed out that invertebrate species have evolved specialized strategies in response to fluctuating water levels. These strategies must be understood if the manager is to duplicate invertebrate production that occurs in natural wetlands. Research on this subject is complicated by sampling problems that can easily lead to erroneous conclusions but this must not deter our quest for better information about these phenomena.

A number of papers were very specific in presenting instructions on how to go about constructing an impoundment. Sandy Verry showed that in the northern Lake States specific conductance can be a useful tool for determining water source for an impoundment when used in conjunction with topography, glacial geology, and soils data. It is then possible to select top candidate sites for impoundment construction. Glen Anderson presented further information on site selection and described various water control structures that have worked well on the Chippewa National Forest. Robert Farmes addressed the same subject and stressed the importance of careful pre-construction planning. He reviewed the various State and local groups that must be contacted and permits that must be obtained. Arlyn Linde drew from past experience in Wisconsin to set guidelines for manipulating vegetation to maintain desired species composition and interspersion. He pointed out that, without proper management, impoundments can easily result in monotypic stands of cattail.

Gerald Martz stressed the importance of public perception of water impoundments. Frequently what the public wants from impoundments may not agree with the wildlife management goals for which they were constructed. For example, impoundments are frequently designed for waterfowl and the public is interested in fishing. Ronald Poff also pointed out the magnitude of public interest in using impoundments for fishing. He illustrated how impoundments differ from natural lakes and some special fish management problems including invasion by rough fish. He furnished the manager with a number of useful but frequently expensive techniques that have been used in Wisconsin. Richard Buech identified another invading species that can cause problems for an impoundment engineer. This animal is often superior to man and usually with a different set of objectives. Numerous ingenious methods of outwitting beavers were illustrated but few worked well. Beavers remain an unsolved problem in impoundment construction. It is important that further research be conducted on total value of impoundments, as well as natural wetlands. We should not have to attempt justification of construction expense on the basis of wildlife use alone.

We found that the papers presented did an excellent job of reviewing the state-of-the-art of impoundment management. A number of new tools were made available for inclusion in a symposium proceedings; however, the complexity of the ecological systems being managed and our frequent lack of basic information means that no proceedings can serve all needs. Because we lack needed information in several areas, impoundment management is still more of an art than a science. The well trained, thoughtful manager intimately familiar with his own area is essential to good wildlife managment. This set of papers should furnish him with much helpful information but cannot replace his own ability to make intuitive decisions.

These new changes are coming under fire by conservation organizations and the Department of Interior as well as some members of Congress. However the nationwide permit must be approved by the individual States, and to date some States, including Minnesota, Wisconsin, and Michigan, I believe, have not approved the nationwide permit under the new regulations. Thus in these States, at least, the old procedure still must be followed. Applications for Corps permits are made through the Office of the District Engineer. Engineering Form 4345 should be requested.

Information on the permit process should be obtained from the regulatory agencies early in the planning stages of an impoundment so that you may be prepared with the proper information when the time comes to submit the application. The process can be a difficult, time-consuming effort until one learns the permit requirements. Just remember that the regulations are designed primarily for the protection of the kinds of waters and wetlands we are all interested in

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Knighton, M. Dean, comp.
Water impoundments for wildlife: a habitat management workshop. Gen. Tech. Rep. NC-100. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 136 p.

Discusses many aspects of managing wildlife water impoundments in the western Great Lakes region. Political and biological justification, where and how to build impoundments, water-level management options, vegetation, water quality, invertebrate populations, and research needs are all considered.

KEY WORDS: Wetland management, waterfowl, low-head dams, water-level control, forests, fish.

North Central Forest Experiment Station

Forest Service--U.S. Department of Agriculture

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CONTENTS

DATA BASES FOR FOREST INVENTORY IN THE NORTH CENTRAL REGION

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The Forest Inventory and Analysis research work unit (FIA) at the North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service, collects information on various renewable natural resources in the 11-State North Central Region (fig. 1). To more efficiently use these data and to make them available to outside users, a commercially available data base management system was used to develop a set of data bases to enhance data storage and retrieval. This report is designed to be used by the managers, researchers, or planners who want to know what information is available from FIA data. Until recently, the only commonly available information was a series of reports that were published when a State

Figure 1.--Forest Survey units and data base boundaries.

Table 1.--Data base date, token, and size by geographic coverage

	Geographic area covered	Date	Token[1/]	Bytes	Cases	Trees	Records	Forest plots
				- - - - - - - - -	- - - - -	Number - - -	- - - - - -	- - - - -
I	Michigan Upper Peninsula	1980	MICHUP	14,034,143	5,719	189,744	246,088	4,709
II	Michigan Lower Peninsula	1980	MICHLP	11,027,555	8,871	125,794	190,840	3,671
III	Northern Wisconsin	1983	WISNOR	15,060,621	7,151	200,351	274,679	5,425
IV	Southern Wisconsin	1983	WISSOU	6,576,303	8,768	89,651	135,884	2,790
V	Northern Minnesota	1977	MINNOR	17,014,071	13,696	235,885	274,804	8,345
VI	Southern Minnesota	1977	MINSOU	5,702,142	22,807	49,060	96,843	2,169
VII	North Dakota	1980	NDAKOTA	2,704,102	18,214	5,339	45,164	604
VIII	South Dakota (eastern)	1980	SDAKOTA	3,333,173	23,206	2,928	50,747	518
IX	Nebraska	1983	NEBRASK	2,314,016	14,449	5,004	35,906	535
X	Kansas	1981	KANSAS	5,371,730	23,705	36,306	93,931	1,807
XI	Iowa	1974	IOWA	2,562,666	12,607	16,276	43,303	756
XII	Missouri Ozarks	1972	MOZARK	4,323,264	4,042	67,956	78,148	2,108
XIII	Missouri Riverborder and Prairies	1972	MORBNW	2,403,360	6,569	27,145	41,470	884
XIV	Illinois[2/]	1962	ILLINI	xx,xxx,xxx	x,xxx	xxx,xxx	xxx,xxx	x,xxx
XV	Indiana[3/]	1967	INDIANA	1,500,725	1,058	24,124	28,028	1,058

[1/]Token used for data base name, password, and security passwords.
[2/]Data for Illinois are not expected to be available until 1985.
[3/]The Indiana data base contains data for forest plots only.

nventory was completed. Because of the exten-ive area covered by the inventories and the arge variety of information gathered, only a mall portion of the available information gets ublished. Persons needing different or more etailed data had to contact FIA personnel irectly to see if the data were available and f so how they could obtain it. This report escribes the FIA data available so that inter-ested persons can decide whether or not those ata can help satisfy their needs. In addition, t serves as a data base description for persons ishing to access the data bases directly. It s not meant to be a complete user's manual for he data base management system.

The FIA data bases are available through he University of Minnesota Computer Center UCC) using the Scientific Information Retrieval SIR) data base management system (Robinson *et al*. 1980). SIR is a hierarchical system desig-ed for use with scientific data. Compared ith other data base management systems avail-ble at UCC, SIR is the easiest, most economical, nd most flexible system available for storing nd retrieving FIA data. Interested users can irectly access the FIA set of data bases and ake their own data retrievals, or they can re-uest the FIA data base manager to develop a specialized data retrieval for them. Users accessing the data bases will need to have a UCC user account, access to a computer terminal, knowledge of the SIR data base management system, and a basic understanding of FIA sampling and estimating procedures. The data base manager can assist anyone seeking a UCC account or information about SIR. Persons requesting the data base manager to access the data bases for them will be charged for computer and personnel costs.

The North Central FIA data base collection is stored in 15 separate SIR data bases, each covering a State or portion of a State (fig. 1, table 1). Within each data base is a data case for each inventory plot. Each case consists of up to seven data record types (table 2). These seven record types relate closely to the way data are collected and used in the FIA inventory.

This report is divided into four sections plus an appendix. The first section briefly describes FIA sampling and estimation procedures as they relate to the seven record types. The second section describes the data base, providing names, descriptions, formats, and data type codes for each variable in the data base.

Table 2.--North central FIA data base record types

Record number	Record name	Record occurrence
1	PLOTALL	All ground plots
2	PLOTFOR	Forest plots and nonforest plots with trees plots
3	TREE	Measured trees on a plot
4	SHRUBT	Measured tall shrubs on a plot
5	SHRUBL	Measured low shrubs on a plot
6	SITETR	Site index trees recorded on a plot
7	POINT	Nonstocked points on a plot

A table of contents and an index of variable names are included. The third section lists the stored procedures contained in the data bases and instructions on their use. The fourth section contains examples of retrievals that can be made from the data bases and demonstrates how interested users may access the data bases. The appendix describes those codes that vary between data bases or whose descriptions are too long to include in section II. The appendix also contains a glossary of terms and definitions used in this and other FIA publications.

SECTION I.--SAMPLING AND ESTIMATION PROCEDURES

Users of the FIA data bases need to understand FIA sampling procedures in order to know the type of information that can be obtained from the data bases, how to go about obtaining this information, and the value and accuracy of the information. Specific FIA sampling procedures differ somewhat from State to State; however, the general description of the sampling procedure given here applies to all States.

The FIA inventory begins with an aerial-photo sample that estimates the area of land by various classes. These classes are based on land-use and, for forested land, forest type, volume, size and/or density. Also, as part of the aerial-photo sample, ground plots are located on the aerial photos and similarly classified. Ground plots may be remeasurement plots, transferred to the aerial photos from old photos or maps, or new plots, selected by systematic sampling. The photo classification of these ground plots, together with the area estimates from the photo sample, is used to assign area expansion factors to the ground plots. If 25 ground plots in the same sampling area have a photo interpretation classification that was observed for 50,000 acres in the sampling area, then each of these 25 ground plots would be given an expansion factor of 2,000 acres (50,000/25). The sampling area, or level at which expansion factors are assigned, is different from State to State, as is the classification scheme used to assign photo-interpretation classes. Sampling areas may be forest survey units (fig. 1), counties, groups of counties, or national forests. Persons interested in the details of how these expansion factors were assigned to the ground plots for a particular area should contact the data base manager.

Once a ground plot location has been selected on an aerial photograph, it is established and measured in the field. On all ground plots the information recorded includes plot location, land use, date of aerial photography, and date of ground measurement. This information is collected for all plots and is stored in record type 1 (PLOTALL), along with two expansion factiors. The first, the area expander (EXPAREA), is recorded for all plots and is used to estimate area based on all sample plots. The second, the remeasurement expander (EXPREMEA), is recorded only for remeasurement plots and is used to make estimates based on the remeasured sample.

On plots that are currently classified as forest or nonforest with trees, and on remeasurement plots that were forest at the previous measurement, additional plot information is recorded in record type 2 (PLOTFOR). This information includes ownership, total basal area, forest type, stand age, site index, and a volume expander (EXPVOL). The volume expander is similar to the area expander, and in most States the two are equal; however, in some States the inventory design necessitated a different expander. The volume expander must be used to expand plot volumes per acre to estimate total volume.

The basic FIA plot is a 10-point cluster that covers a 1-acre sample area. At each sample point a 37.5 BAF (English) prism plot is established, and all live trees with a diameter breast height (d.b.h.) 5 inches or greater are sampled, as well as salvagable dead trees or those that have died in the past 3 years. Trees with a d.b.h.less than 5 inches but at least 1 inch are sampled on fixed-radius (6.8 feet) plots. Stumps cut in the past 3 years are recorded on ten 1/50-acre plots. Each tallied tree or stump is identified by a unique point and tree number. Items tallied include species d.b.h., crown ratio, and other tree information. This information is stored in record type 3 (TREE). There is one occurrence of this record for each tree. Some of the items in this record, such as tree volume, are computed from basic tree measurements. There is also an expander for each tree (EXPANDR) that expresses the number of trees per acre represented by the sample tree.

Shrubs are sampled on the northeast quarter of a 6.8-foot fixed-radius plot located at each of the first three cluster sample points. Shrubs are tallied as tall or low. Tall shrub species and stem diameter are recorded in record type 4 (SHRUBT), and low shrub species and percent cover are recorded in record type 5 (SHRUBL).

Also, for each forest plot a number of additional trees are measured to determine site index. This information is recorded in record type 6 (SITETR) and occurs once for each site index tree that was measured. In addition, when one of the 10-point cluster sample points is observed to be nonstocked (no trees or seedlings present), an explanation of why it is nonstocked is recorded in record type 7 (POINT).

For remeasurement plots additional information is recorded for each tree, such as original tree d.b.h. and other original tree data. This information may be used to estimate growth, mortality, and removals on these remeasurement plots. On new plots removals can be estimated using the measured stumps and assuming these

stumps were cut in the past 3 years. Mortality on new plots can be estimated from the dead trees tallied, also assuming these trees died in the past 3 years.

Another method to estimate mortality using new plots is by using the mortality factor, an estimate of the number of trees per acre represented by the tally tree that will die in the next year. This mortality factor is the product of the tree expander and the probability that the tree will die in the next year. Growth on new plots is estimated using data stored as original tree data. For new plots, the original tree data are an estimate of the trees' condition 1 year before being measured, based on growth functions. These growth functions and the functions used to compute probability of mortality are derived from remeasurement plots. Details about these functions for a particular data base can be obtained by contacting the data base manager.

Finally, the data bases also contain projected plot and tree data that are periodically updated using the Stand and Tree Evaluation and Modeling System (STEMS) (Belcher et al. 1982) growth model. The system used to update the data simulates natural growth and mortality but does not account for removals, land-use change, regeneration, fire, management, or any other major changes that could occur. Methods are being developed to incorporate these major changes into the update process.

Not all data were collected for all surveys. For example, shrub data were first collected during the 1980 Michigan survey and are only available for this and subsequent surveys. If a data item is not available for all surveys, this is noted in the codebook (section II).

SECTION II.--CODEBOOK DEFINITION

Codebook Format Explanation

The codebook contains detailed definitions of the variables in the data base. A detailed explanation of this codebook can be found in the SIR user's manual (Robinson et al. 1980). We present a brief explanation of this format using the definition of sample kind as an example.

```
R2.     SAMPKND , Sample Kind
               FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:

               (1) New 10-Point Full
               (2) Remeasurement
               (3) Remeasurement NF
               (4) New 10-Point Full NF
               (5) Reserve [Phantom]
               (6) Remeasurement Partial
               (7) New 10-Point Partial
               (8) Remeasurement Partial
               (9) Remeasurement Updated
               (0) Stereo dots [not gr.ck]
```

Each definition starts with a variable number consisting of a letter (C or R) and one or more digits. A description of the difference between C (common information record) and R (record) variables can be found in Robinson et al. 1980. In the example the variable number is R2. Next is the variable name, one to eight characters all upper case, SAMPKND in the example. The name is followed by the variable label. This label can be of any length and consists of two parts: A short label of up to 40 characters followed by a semi-colon and as many 80-character lines separated by semi-colons as desired. The example has a short label only. This short label is the label transferred with the variable during retrievals. The next line shows the data input format for the variable, in this case a one-digit integer number, followed by the data type and data base storage requirement, in the example an integer variable using one byte of storage. Finally, the value labels are listed. These labels are up to 20 characters long and are listed for each legal value. In the example, we have labels for each of the 10 possible values. In general, if a value label does not exist, it means that the remaining values are illegal for that variable.

NORTH CENTRAL FIA DATA BASE CODEBOOK DEFINITION

TABLE OF CONTENTS

RECORD 1 (PLOTALL)

RECORD 2 (PLOTFOR)

1/ C = Common Information Record (CIR) variable
R = Record variable.

RECORD 2 (PLOTFOR) -(continued)

Variable name	Variable type & number[1/]	Definition	Page
SZDNPRJ	R22.	Projected Stand Size-Density	14
FORTORG	R23.	Original Forest Type	14
SZDNORG	R24.	Original Stand Size-Density	14
STDAGE	R25.	Stand Age	14
PRJAGE	R26.	Projected Stand Age	14
SITECLS	R27.	Site Class	14
SITEIND	C5.	Site Index	14
SISPP	R28.	Site Index Species	14
EXPVOL	R29.	Volume Expander	14
GSCUVS	R30.	Growing Stock CuFt Volume Softwoods	15
GSCUVH	R31.	Growing Stock CuFt Volume Hardwoods	15
PRJSVOL	R32.	Projected G.S. CuFt Volume Softwoods	15
PRJHVOL	R33.	Projected G.S. CuFt Volume Hardwoods	15
STDAREA	R34.	Stand Area	15
AREACOND	R35.	Stocking Level Class	15
GRSTKPC	R36.	Growing Stock Tree Stocking	15
ROUGHPC	R37.	Rough Tree Stocking	16
ROTENPC	R38.	Rotten Tree Stocking	16
PRJGSPC	R39.	Projected G.S. Tree Stocking	16
PRJRGPC	R40.	Projected Rough Tree Stocking	16
PRJRTPC	R41.	Projected Rotten Tree Stocking	16
SG01	C8.	Presence or Absence of Jack Pine	15
SG02	C9.	Presence or Absence of Red Pine	15
SG03	C10.	Presence or Absence of White Pine	15
SG04	C11.	Presence or Absence of Ponderosa Pine	15
SG05	C12.	Presence or Absence of Loblolly Pine	15
SG06	C13.	Presence or Absence of Shortleaf Pine	15
SG07	C14.	Presence or Absence of Other Yellow Pines	15
SG08	C15.	Presence or Absence of White Spruce	15
SG09	C16.	Presence or Absence of Black Spruce	15
SG10	C17.	Presence or Absence of Balsam Fir	15
SG11	C18.	Presence or Absence of Hemlock	15
SG12	C19.	Presence or Absence of Tamarack	15
SG13	C20.	Presence or Absence of Bald Cypress	15
SG14	C21.	Presence or Absence of E. Red Cedar	15
SG15	C22.	Presence or Absence of N. white-cedar	15
SG16	C23.	Presence or Absence of (not assigned)	15
SG17	C24.	Presence or Absence of Other Softwoods	15
SG18	C25.	Presence or Absence of Select White Oak	15
SG19	C26.	Presence or Absence of Other White Oak	15
SG20	C27.	Presence or Absence of Select Red Oak	15
SG21	C28.	Presence or Absence of Other Red Oak	16
SG22	C29.	Presence or Absence of Select Hickory	16
SG23	C30.	Presence or Absence of Other Hickory	16
SG24	C31.	Presence or Absence of Basswood	16
SG25	C32.	Presence or Absence of Beech	16
SG26	C33.	Presence or Absence of Yellow Birch	16
SG27	C34.	Presence or Absence of Hard Maple	16
SG28	C35.	Presence or Absence of Soft Maple	16
SG29	C36.	Presence or Absence of Elm	16
SG30	C37.	Presence or Absence of Black Ash	16
SG31	C38.	Presence or Absence of White-Green Ash	16
SG32	C39.	Presence or Absence of Sycamore	16
SG33	C40.	Presence or Absence of Cottonwood	16
SG34	C41.	Presence or Absence of Willow	16
SG35	C42.	Presence or Absence of Hackberry	16
SG36	C43.	Presence or Absence of Balsam Poplar	16
SG37	C44.	Presence or Absence of Bigtooth Aspen	16
SG38	C45.	Presence or Absence of Quaking Aspen	16
SG39	C46.	Presence or Absence of Paper Birch	16
SG40	C47.	Presence or Absence of River Birch	16
SG41	C48.	Presence or Absence of Sweetgum	16
SG42	C49.	Presence or Absence of Blackgum and Tupelo	16
SG43	C50.	Presence or Absence of Black Cherry	16

[1/] C = Common Information Record (CIR) variable
R = Record variable

RECORD 2 (PLOTFOR) -(continued)

Variable name	Variable type & number[1/]	Definition	Page
SG44	C51.	Presence or Absence of Black Walnut	16
SG45	C52.	Presence or Absence of Butternut	16
SG46	C53.	Presence or Absence of Yellow Poplar	16
SG47	C54.	Presence or Absence of (not assigned)	16
SG48	C55.	Presence or Absence of (not assigned)	16
SG49	C56.	Presence or Absence of Other Hardwoods	16
SG50	C57.	Presence or Absence of Noncommercial	16

RECORD 3 (TREE)

Variable name	Variable type & number[1/]	Definition	Page
IDENT	C6.	Case Identifier	17
TRNUM	R1.	Tree Number	17
TRHIST	R2.	Tree History-Status	17
PRJHIST	R3.	Projected Tree History-Status	17
SPECIES	R4.	Tree Species	17
DBHORG	R5.	Original Diameter Breast High	17
DBHCUR	R6.	Current Diameter Breast High	17
DBHPRJ	R7.	Projected Diameter Breast High	17
SOUND	R8.	Soundness Code	17
LOGGR	R9.	Log Grade	18
CAVIT	R10.	Cavities Code	18
CRRAT	R11.	Crown Ratio	18
PRJCRRAT	R12.	Projected Crown Ratio	18
CRCLS	R13.	Crown Class	18
DAMDETH	R14.	Damage Cause of Death	18
TRCLS	R15.	Tree Class	18
PRJTRCLS	R16.	Projected Tree Class	18
PTOCC	R17.	Point Occupancy	18
EXPANDR	R18.	Number of Trees Per Acre	18
PRJEXPD	R19.	Projection Factor	18
MORTFAC	R20.	Mortality Factor	18
NCSPGP	R21.	North Central Species Group	19
TRSZCLS	R22.	Tree Size Class	19
PRJTRSZ	R23.	Projected Tree Size Class	19
TRSIND	R24.	Tree Site Index	19
NETCUVL	R25.	Net Cubic Foot Volume in Tree	19
PRJNCVL	R26.	Projected Net CuFt Volume in Tree	19

RECORD 4 (SHRUBT)

			Page
IDENT	C6.	Case Identifier	20
SBTNUM	R1.	Shrub Number-Tall	20
SHRUBSP	R2.	Shrub Species-Tall	20
DIACLS	R3.	Diameter Class	20
COUNT	R4.	Count of Number of Individuals	20
EXPSHUT	R5.	Expander for Shrub Tall	20

RECORD 5 (SHRUBL)

			Page
IDENT	C6.	Case Identifier	20
SBLNUM	R1.	Shrub Number-Low	20
SHUSPL	R2.	Shrub Species-Low	20
COVER	R3.	Percent Ground Cover	21
EXPSHUL	R4.	Expander for Low Shrub	21

RECORD 6 (SITETR)

			Page
IDENT	C6.	Case Identifier	21
TRNUM	R1.	Tree Number	21
DBHSI	R2.	Diameter Breast High Site Index Tre	21
SPPSI	R3.	Species Site Index Tree	21
HTSI	R4.	Height Site Index Tree	21
AGESI	R5.	Total Age Site Index Tree	21
YRSADD	R6.	Years Added to DBH Age for Total Ag	21

[1/] C = Common Information Record (CIR) variable
R = Record variable.

RECORD 7 (POINT)

1/C = Common Information Record (CIR) variable
R = Record variable.

This data base contains data for an entire State or a portion of State. The code book is the same for the entire State. Each case contains the data from one survey plot in seven record types. Record types 1 and 2 contain plot level data and record types 3 through 7 contain tree and shrub data.

*** RECORD 1 (PLOTALL) DEFINITION ***

Record type 1 (PLOTALL) contains data gathered for all plots.

```
MAXIMUM RECS/CASE:   1
CASE IDENTIFIER:     IDENT (A)

C6.     IDENT   , Case Identifier
                  (XYYYYY where;
                   X = FIA unit number
                   YYYYY = Plot number.
                   Every plot within a data base
                   has a unique case identifier.
                   See appendix for unit codes.)
                FORMAT:  I6
             DATA TYPE:  I*4

R1.     STATE   , State Code
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (17) Illinois  (26) Michigan   (38) North Dakota
                         (18) Indiana   (27) Minnesota  (46) South Dakota
                         (19) Iowa      (29) Missouri   (55) Wisconsin
                         (20) Kansas    (31) Nebraska

C1.     UNTCO   , Unit and County
                  (XYY where;
                   X = Unit Number
                   YY = County number.
                   See appendix for codes)
                FORMAT:  I3
             DATA TYPE:  I*2

R2.     SAMPKND , Sample Kind
                FORMAT:  I1
             DATA TYPE:  I*1
          VALUE LABELS:
             (1) New 10-Point Full               (6) Remeasurement Partial
             (2) Remeasurement                   (7) New 10-Point Partial
             (3) Remeasurement NF                (8) Remeasurement Partial
             (4) New 10-Point Full NF            (9) Remeasurement Updated
             (5) Reserve[Phantom]                (0) Stereo dots [not gr.ck]

R3.     DISTURB , Disturbance Code
                  Not used prior to 1982
                FORMAT:  I1
             DATA TYPE:  I*1
          VALUE LABELS:
             (1) Forest to forest undisturbed    (4) Forest to nonforest
             (2) Nonforest to forest disturbed   (5) Nonforest to nonforest
             (3) Nonforest to forest

R4.     PICODE  , Photo Interpretation Code
                 (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2
```

```
R5.     PISTRAT , Photo Stratification Code
                 (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2

C2.     GLUCUR  , Ground Land Use Current
R6.     GLUORG  , Ground Land Use Original
R7.     GLUPRJ  , Ground Land Use Projected
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (20) Commercial Forest    (21) Pastured Com. Fore:
                         (22) Plantation           (40) Unproductive Forest
                         (41) Reserved Forest      (45) Reserved For.Prod.
                         (46) Christmas Tr.Plant.  (51) Cropland With Trees
                         (52) Pasture With Trees   (53) Wooded Strip
                         (54) Idle Farmland W-T    (55) Marsh With Trees
                         (56) Narrow Windbreaks    (57) Wide Windbreaks
                         (58) Windbreaks           (59) Wooded Pasture
                         (61) Cropland Wo-T        (62) Improved Pasture Wo-
                         (64) Idle Farmland Wo-T   (65) Marsh Wo-T
                         (66) Other Farmland       (67) Urban and Other
                         (68) Rights-of-way        (69) Nonforest Reserve
                         (71) Urban For. Reserved  (72) Urban With Trees
                         (80) Noncensus Water      (90) Census Water


R8.     CHANGE  , Reason for GLU change
                FORMAT:  I1
             DATA TYPE:  I*1

R9.     UTREND  , Use Trend
                  See appendix for deff.
                FORMAT:  I3
             DATA TYPE:  I*2

R10.    STDHIST , Stand History
                  See appendix for deff.
                FORMAT:  I2
             DATA TYPE:  I*2

R11.    PRJSTDH , Projected Stand History
                  See appendix for deff.
                FORMAT:  I2
             DATA TYPE:  I*2

R12.    PHOTAGE , Photo Age
                  (years)
                FORMAT:  I1
             DATA TYPE:  I*1

R13.    SURDATE , Survey Date
                FORMAT:  A4  WITH DATE MAP: 'MMYY'
             DATA TYPE:  I*4

R14.    PRJDATE , Projected Date
                FORMAT:  A4  WITH DATE MAP: 'MMYY'
             DATA TYPE:  I*4

R15.    GROPER  , Remeasurement Peroid
                  (years)
                FORMAT:  I2
             DATA TYPE:  I*2

R16.    USESET  , Use Setting-Recreation
                  Not used prior to 1982
                FORMAT:  I1
             DATA TYPE:  I*1
          VALUE LABELS:  (1) Primitive             (2) Semi-prim. non-mot
                         (3) Semi-prim. motor      (4) Roaded natural
                         (5) Rural                 (6) Urban
```

R17. USEAREA , Use Area-Recreation
Not used prior to 1982
FORMAT: I1
DATA TYPE: I*1

R18. USEPOST , Use Posted-Recreation
Not used prior to 1982
FORMAT: I1
DATA TYPE: I*1

R19. SOILCLS , Soil Classification
Available for future use
FORMAT: I8
DATA TYPE: I*4

C7. EXPAREA , Area Expander
(acres)
FORMAT: I5
DATA TYPE: I*4

R20. PRJAREA1, Projected Area Expander 1
(acres)
FORMAT: I5
DATA TYPE: I*4

R21. PRJAREA2, Projected Area Expander 2
(acres)
FORMAT: I5
DATA TYPE: I*4

R22. UTMZONE , UTM Zone Code
FORMAT: I2
DATA TYPE: I*2

R23. UTMNORTH, UTM Northing To Nearest 1000 Meters
FORMAT: I5
DATA TYPE: I*4

R24. UTMEAST , UTM Easting To Nearest 1000 Meters
FORMAT: I5
DATA TYPE: I*4

R25. TOWNSHIP, Township
FORMAT: A4
DATA TYPE: A*6

R26. RANGE , Range
FORMAT: A4
DATA TYPE: A*6

R27. SECTION , Section
FORMAT: I2
DATA TYPE: I*2

R28. EXPREMEA, Remeasurement Expander
(acres)
FORMAT: I6
DATA TYPE: I*4

RECORD 2 (PLOTFOR) DEFINITION ***

Record type 2 (PLOTFOR) contains data for plots classified as forest, at either measurement occasion for remeasurement plots, or for plots classified as non-forest with trees.

```
MAXIMUM RECS/CASE:     1
CASE IDENTIFIER:       IDENT (A)

C6.     IDENT    , Case Identifier
                   (Unit & Seq.Plot Num.)
                 FORMAT:  I6
              DATA TYPE:  I*4

R1.     DWT      , Distance to Water Type
                   Not used prior to 1974
                 FORMAT:  I1
              DATA TYPE:  I*1
           VALUE LABELS:  (1) Streams                (2) Lakes
                          (3) Swamps                 (4) Farm ponds

R2.     DWS      , Distance to Water Size of Water
                   (acres)
                   Not used prior to 1982
                 FORMAT:  I3
              DATA TYPE:  I*2

R3.     DWV      , Distance to Water Value
                   (chains)
                   Not used prior to 1974
                 FORMAT:  I4
              DATA TYPE:  I*2

R4.     DRT      , Distance to Road Type of Road
                   Not used prior to 1974
                 FORMAT:  I1
              DATA TYPE:  I*1
           VALUE LABELS:  (1) Paved-4 lane           (2) Paved-2 lane
                          (3) Improved-gravel

R5.     DRV      , Distance to Road Value
                   (chains)
                   Not used prior to 1974
                 FORMAT:  I4
              DATA TYPE:  I*2

R6.     NATFOR   , National Forest Code
                 FORMAT:  I3
              DATA TYPE:  I*2
           VALUE LABELS:  (902) Chequamegon          (903) Chippewa
                          (904) Huron-Manistee       (906) Nicolet
                          (907) Ottawa               (908) Shawnee
                          (909) Superior             (910) Hiawatha
                          (911) Wayne-Hoosier        (918) Mark Twain

R7.     RANDIST  , Ranger District
                 FORMAT:  I2
              DATA TYPE:  I*2

C3.     OWNGP    , Ownership Group
                 FORMAT:  I1
              DATA TYPE:  I*1
           VALUE LABELS:  (1) National forest        (2) Other public
                          (3) Private
```

```
R8.     PRJOWN  , Projected Owner Group
                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (1) National forest      (2) Other public
                        (3) Private

R9.     ASPECT  , Aspect of Plot Center
                  (degrees)
                  Not used prior to 1973
                FORMAT:  I3
            DATA TYPE:  I*2

R10.    POSITION, Position on Slope
                  Not used prior to 1973
                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (1) Top quarter          (2) Upper quarter
                        (3) Lower quarter        (4) Level or lowest quarter

R11.    SLOPE   , Slope Angle at Plot Center
                  (percent)
                  Not used prior to 1973
                FORMAT:  I2
            DATA TYPE:  I*2

R12.    PHYCLS  , Physiographic Class
                  (Degree of Wet-Dryness)
                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (3) Xeric                (4) Xeromesic
                        (5) Mesic                (6) Hydromesic
                        (7) Hydric

R13.    STDORG  , Stand Origin
                  (Planted-Natural)

                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (1) Natural              (2) GE 40 percent artificial
                        (3) LT 40 percent artificial

R14.    SEEDSOR , Seed Source
                  (Degree of Conifer Seed Source)
                FORMAT:  I1
            DATA TYPE:  I*1
        VALUE LABELS    (1) Adequate softwood    (2) Adequate hardwood
                        (3) Adeq.soft & hard     (4) Inadequate all spp.

R15.    CUNCOND , Conifer Understory Condition
                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (1) None or inadequate   (2) Planted adequate
                        (3) Planted needs treat. (4) Natural adequate
                        (5) Natural needs treat.

R16.    CUNSPP  , Conifer Understory Species
                 (See appendix for codes)
                FORMAT:  I3
            DATA TYPE:  I*2

R17.    BACUR   , Basal Area Current Value
                  (sq feet)
                FORMAT:  I3
            DATA TYPE:  I*2

R18.    BAORG   , Basal Area Original Value
                  (sq feet)
                FORMAT:  I3
            DATA TYPE:  I*2
```

```
R19.    BAPRJ    , Basal Area Projected Value
                   (sq feet)
                FORMAT:  I3
             DATA TYPE:  I*2

C4.     FORTCUR  , Current Forest Type
                  (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2

R20.    FORTPRJ  , Projected Forest Type
                  (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2

R21.    SZDNCUR  , Current Stand Size-Density

R22.    SZDNPRJ  , Projected Stand Size-Density
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (11) Sawtimber-Good       (21) Poletimber-Good
                         (12) Sawtimber-Medium     (22) Poletimber-Medium
                         (13) Sawtimber-Poor       (23) Poletimber-Poor
                         (31) Seed-Saps-Good       (40) Nonstocked
                         (32) Seed-Saps-Medium
                         (33) Seed-Saps-Poor

R23.    FORTORG  , Original Forest Type
                  (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2

R24.    SZDNORG  , Original Stand Size-Density
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (10) Sawtimber            (20) Poletimber
                         (30) Sapling & seedling   (40) Nonstocked

R25.    STDAGE   , Stand Age
                   (years)
                FORMAT:  I3
             DATA TYPE:  I*2

R26.    PRJAGE   , Projected Stand Age
                   (years)
                FORMAT:  I3
             DATA TYPE:  I*2

R27.    SITECLS  , Site Class
                FORMAT:  I1
             DATA TYPE:  I*1
          VALUE LABELS:  (1) 225+ cu.ft.
                         (2) 165 to 225 cu.ft.
                         (3) 120 to 165 cu.ft.
                         (4) 85 to 120 cu.ft.
                         (5) 50 to 85 cu.ft.
                         (6) Less than 50 cu.ft.

C5.     SITEIND  , Site Index
                   (feet at age 50)
                FORMAT:  I2
             DATA TYPE:  I*2

R28.    SISPP    , Site Index Species
                  (See appendix for codes)
                FORMAT:  I3
             DATA TYPE:  I*2

R29.    EXPVOL   , Volume Expander
                   (acres)
                FORMAT:  I5
             DATA TYPE:  I*4
```

R30. GSCUVS , Growing Stock CuFt Volume Softwoods
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

R31. GSCUVH , Growing Stock CuFt Volume Hardwoods
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

R32. PRJSVOL , Projected G.S. CuFt Volume Softwoods
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

R33. PRJHVOL , Projected G.S. CuFt Volume Hardwoods
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

R34. STDAREA , Stand Area
(acres)
FORMAT: I3
DATA TYPE: I*2

R35. AREACOND, Stocking Level Class
(See appendix for codes)
FORMAT: I2
DATA TYPE: I*2

R36. GRSTKPC , Growing Stock Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

Variables C8 (SG01) through C57 (SG50) indicate the presence or absence of a particular species group on the plot. For example, SG01 indicates the presence or absence of jack pine on the plot. If SG01 is 0, then no jack pine was found on the plot. SG01 is 1 when jack pine seedling and/or sapling trees were found, but jack pine poletimber or sawtimber was not. SG01 is 2, jack pine poletimber, but not sawtimber, was present; if SG01 is 3, jack pine sawtimber was present.

C8. SG01 , Presence or Absence of Jack Pine
C9. SG02 , Presence or Absence of Red Pine
C10. SG03 , Presence or Absence of White Pine
C11. SG04 , Presence or Absence of Ponderosa Pine
C12. SG05 , Presence or Absence of Loblolly Pine
C13. SG06 , Presence or Absence of Shortleaf Pine
C14. SG07 , Presence or Absence of Other Yellow Pine
C15. SG08 , Presence or Absence of White Spruce
C16. SG09 , Presence or Absence of Black Spruce
C17. SG10 , Presence or Absence of Balsam Fir
C18. SG11 , Presence or Absence of Hemlock
C19. SG12 , Presence or Absence of Tamarack
C20. SG13 , Presence or Absence of Bald Cypress
C21. SG14 , Presence or Absence of E. Red Cedar
C22. SG15 , Presence or Absence of N. White-cedar
C23. SG16 , Presence or Absence of (not assigned)
C24. SG17 , Presence or Absence of Other Softwoods
C25. SG18 , Presence or Absence of Select White Oak
C26. SG19 , Presence or Absence of Other White Oak
C27. SG20 , Presence or Absence of Select Red Oak

C28. SG21 , Presence or Absence of Other Red Oak
C29. SG22 , Presence or Absence of Select Hickory
C30. SG23 , Presence or Absence of Other Hickory
C31. SG24 , Presence or Absence of Basswood
C32. SG25 , Presence or Absence of Beech
C33. SG26 , Presence or Absence of Yellow Birch
C34. SG27 , Presence or Absence of Hard Maple
C35. SG28 , Presence or Absence of Soft Maple
C36. SG29 , Presence or Absence of Elm
C37. SG30 , Presence or Absence of Black Ash
C38. SG31 , Presence or Absence of White-Green Ash
C39. SG32 , Presence or Absence of Sycamore
C40. SG33 , Presence or Absence of Cottonwood
C41. SG34 , Presence or Absence of Willow
C42. SG35 , Presence or Absence of Hackberry
C43. SG36 , Presence or Absence of Balsam Poplar
C44. SG37 , Presence or Absence of Bigtooth Aspen
C45. SG38 , Presence or Absence of Quaking Aspen
C46. SG39 , Presence or Absence of Paper Birch
C47. SG40 , Presence or Absence of River Birch
C48. SG41 , Presence or Absence of Sweet Gum
C49. SG42 , Presence or Absence of Black Gum and Tupelo
C50. SG43 , Presence or Absence of Black Cherry
C51. SG44 , Presence or Absence of Black Walnut
C52. SG45 , Presence or Absence of Butternut
C53. SG46 , Presence or Absence of Yellow Poplar
C54. SG47 , Presence or Absence of (not assigned)
C55. SG48 , Presence or Absence of (not assigned)
C56. SG49 , Presence or Absence of Other Hardwoods
C57. SG50 , Presence or Absence of Noncommercial
FORMAT: I1
DATA TYPE: I*1
VALUE LABELS: (1) Sapling & seedling (2) Poletimber (3) Sawtimber

R37. ROUGHPC , Rough Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

R38. ROTENPC , Rotten Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

R39. PRJGSPC , Projected G.S. Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

R40. PRJRGPC , Projected Rough Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

R41. PRJRTPC , Projected Rotten Tree Stocking
(percent)
FORMAT: I3
DATA TYPE: I*2

*** RECORD 3 (TREE) DEFINITION ***

Record type 3 (TREE) contains the individual tree data tallied on each plot. The species group variable is set at 1, 2, or 3 on the CIR if a species group is present on the plot; otherwise it is blank or missing, indicating that the species is not present.

```
MAXIMUM RECS/CASE:   250
CASE IDENTIFIER:     IDENT (A)
SORT IDENTIFIER: (1) TRNUM (A)

C6.     IDENT   , Case Identifier
                  (Unit & Seq.Plot Num.)
              FORMAT:  I6
           DATA TYPE:  I*4

R1.     TRNUM   , Tree Number
              FORMAT:  I4
           DATA TYPE:  I*2

R2.     TRHIST  , Tree History-Status
                  On remeasurement plots the first
                  digit is original status, the
                  second digit is current status
              FORMAT:  I2
           DATA TYPE:  I*2
        VALUE LABELS:  (0) No status              (1) Growing stock live
                       (2) Cull live              (3) Ingrowth
                       (4) Dead[salvable]         (5) Dead[mortality]
                       (6) Ongrowth               (7) Stump[salvaged]
                       (8) Stump[utilized]        (9) Stump[not utilized]

R3.     PRJHIST , Projected Tree History-Status
              FORMAT:  I1
           DATA TYPE:  I*1
        VALUE LABELS:  (0) No status              (1) Growing stock live
                       (2) Cull live              (3) Ingrowth
                       (5) Dead[mortality]        (8) Stump[utilized]

R4.     SPECIES , Tree Species
                 (See appendix for codes)
              FORMAT:  I3
           DATA TYPE:  I*2

R5.     DBHORG  , Original Diameter Breast High
                  (inches)
              FORMAT:  D4.2
           DATA TYPE:  R*8

R6.     DBHCUR  , Current Diameter Breast High
                  (inches)
              FORMAT:  D4.2
           DATA TYPE:  R*8

R7.     DBHPRJ  , Projected Diameter Breast High
                  (inches)
              FORMAT:  D4.2
           DATA TYPE:  R*8

R8.     SOUND   , Soundness Code
              FORMAT:  I1
           DATA TYPE:  I*1

R9.     LOGGR   , Log Grade
              FORMAT:  I1
           DATA TYPE:  I*1
```

```
R10.    CAVIT   , Cavities Code not used prior to 1981
                 (See appendix for codes)
                FORMAT:  I2
             DATA TYPE:  I*2

R11.    CRRAT   , Crown Ratio
                  (percent live crown)
                FORMAT:  I1
             DATA TYPE:  I*1

R12.    PRJCRRAT, Projected Crown Ratio
                  (percent live crown)
                FORMAT:  I1
             DATA TYPE:  I*1

R13.    CRCLS   , Crown Class
                FORMAT:  I1
             DATA TYPE:  I*1
          VALUE LABELS:  (1) Open grown           (2) Dominant
                         (3) Codominant           (4) Intermediate
                         (5) Overtopped

R14.    DAMDETH , Damage Cause of Death
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (0) None                 (10) Insect
                         (11) Poplar borer        (20) Disease
                         (21) Phellinus tremulae  (22) Hypoxylon canker
                         (23) Other cankers       (24) Blister rust
                         (25) Dwarf mistletoe     (26) Shoot blights
                         (27) Butternut canker    (28) Nectria canker
                         (29) Eutypella canker    (30) Fire
                         (40) Animal              (41) Beaver
                         (42) Cattle              (43) Deer
                         (44) Porcupine           (45) Sapsuckers
                         (50) Weather             (60) Suppression
                         (70) Unknown             (71) Missing or dead top
                         (72) Poor form           (80) Logging
                         (81) Logging             (82) Timber stand imp.
                         (84) Land clearing       (85) Conversion

R15.    TRCLS   , Tree Class
R16.    PRJTRCLS, Projected Tree Class
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (10) Growing stock des.  (20) Growing stock acc.
                         (30) Cull rough          (31) Cull short-log
                         (40) Cull rotten

R17.    PTOCC   , Point Occupancy
                FORMAT:  I1
             DATA TYPE:  I*1

R18.    EXPANDR , Number of Trees Per Acre
                FORMAT:  D4.2
             DATA TYPE:  R*8

R19.    PRJEXPD , Projection Factor
                  (num. trees per acre)
                FORMAT:  D4.2
             DATA TYPE:  R*8

R20.    MORTFAC , Mortality Factor
                  (num. trees per acre per year)
                FORMAT:  D4.2
             DATA TYPE:  R*8
```

R21. NCSPGP , North Central Species Group
FORMAT: I2
VALUE LABELS:

(1) Jack pine	(2) Red pine
(3) White pine	(4) Ponderosa pine
(5) Loblolly pine	(6) Shortleaf pine
(7) Other yellow pines	(8) White spruce
(9) Black spruce	(10) Balsam fir
(11) Hemlock	(12) Tamarack
(13) Bald cypress	(14) Eastern redcedar
(15) Northern white-cedar	(16)
(17) Other softwoods	(18) Select white oak
(19) Other white oak	(20) Select red oak
(21) Other red oak	(22) Select hickory
(23) Other hickory	(24) Basswood
(25) Beech	(26) Yellow birch
(27) Hard maple	(28) Soft maple
(29) Elm	(30) Black ash
(31) White & green ash	(32) Sycamore
(33) Cottonwood	(34) Willow
(35) Hackberry	(36) Balsam poplar
(37) Bigtooth aspen	(38) Quaking aspen
(39) Paper birch	(40) River birch
(41) Sweetgum	(42) Blackgum and tupelo
(43) Black cherry	(44) Black walnut
(45) Butternut	(46) Yellow poplar
(47)	(48)
(49) Other hardwoods	(50) Noncommercial spp.

R22. TRSZCLS , Tree Size Class
FORMAT: I1
DATA TYPE: I*1
VALUE LABELS: (1) Sapling & seedling (2) Poletimber
(3) Sawtimber

R23. PRJTRSZ , Projected Tree Size Class
FORMAT: I1
DATA TYPE: I*1
VALUE LABELS: (1) Seeds & saps
(2) Poletimber
(3) Sawtimber

R24. TRSIND , Tree Site Index
(feet age 50)
FORMAT: I2
DATA TYPE: I*2

R25. NETCUVL , Net Cubic Foot Volume in Tree
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

R26. PRJNCVL , Projected Net CuFt Volume in Tree
(cubic feet per acre)
FORMAT: I6
DATA TYPE: I*4

RECORD 4 (SHRUBT) DEFINITION ***

Record type 4 (SHURBT) contains the data tallied for tall woody shrubs on forest plots.

```
MAXIMUM RECS/CASE:   100
CASE IDENTIFIER:     IDENT (A)
SORT IDENTIFIER: (1) SBTNUM (A)

C6.     IDENT   , Case Identifier
                  (Unit & Seq.Plot Num.)
                FORMAT:  I6
             DATA TYPE:  I*4

R1.     SBTNUM  , Shrub Number-Tall
                FORMAT:  I4
             DATA TYPE:  I*2

R2.     SHRUBSP , Shrub Species-Tall
                 (See appendix for codes)
                FORMAT:  I3
             DATA TYPE:  I*2

R3.     DIACLS  , Diameter Class
                  (inches)
                FORMAT:  I2
             DATA TYPE:  I*2
          VALUE LABELS:  (1) 0.0-0.19       (2) 0.2-0.29
                         (3) 0.3-0.39       (4) 0.4-0.49
                         (5) 0.5-0.99       (10) 1.0-1.49
                         (15) 1.5-1.99      (20) 2.0-2.49
                         (25) 2.5-2.99      (30) 3.0-3.49
                              etc.

R4.     COUNT   , Count of Number of Individuals
                FORMAT:  I3
             DATA TYPE:  I*2

R5.     EXPSHUT , Expander for Shrub Tall
                  (shrubs per acre)

                FORMAT:  D4.2
             DATA TYPE:  R*8
```

*** RECORD 5 (SHRUBL) DEFINITION ***

Record type 5 (SHRUBL) contains the data tallied for low herbaceous shrubs on forest plots.

```
MAXIMUM RECS/CASE:   30
CASE IDENTIFIER:     IDENT (A)

SORT IDENTIFIER: (1) SBLNUM (A)

C6.     IDENT   , Case Identifier
                  (Unit & Seq.Plot Num.)
                FORMAT:  I6
             DATA TYPE:  I*4

R1.     SBLNUM  , Shrub Number-Low
                FORMAT:  I4
             DATA TYPE:  I*2

R2.     SHUSPL  , Shrub Species-Low
                 (See appendix for codes)
                FORMAT:  I3
             DATA TYPE:  I*2
```

```
R3.     COVER    , Percent Ground Cover
                FORMAT:  I1
            DATA TYPE:  I*1
         VALUE LABELS:  (1) Solitary Plant         (2) Few Plants LT 5 percent
                        (3) Numerous Plants        (4) 5-25 percent
                        (5) 25-50 percent          (6) 50-90 percent
                        (7) 90-100 percent

R4.     EXPSHUL  , Expander for Low Shrub
                   (shrubs per acre)
                FORMAT:  D4.2
            DATA TYPE:  R*8
```

*** RECORD 6 (SITETR) DEFINITION ***

Record type 6 (SITETR) contains data tallied for site trees on forest plots.

```
MAXIMUM RECS/CASE:    10
CASE IDENTIFIER:      IDENT (A)

SORT IDENTIFIER: (1) TRNUM (A)

C6.     IDENT    , Case Identifier
                   (Unit & Seq.Plot Num.)
                FORMAT:  I6
            DATA TYPE:  I*4

R1.     TRNUM    , Tree Number
                FORMAT:  I4
            DATA TYPE:  I*2

R2.     DBHSI    , Diameter Breast High Site Index Tree
                   (inches)
                FORMAT:  D3.1
            DATA TYPE:  R*8

R3.     SPPSI    , Species Site Index Tree
                  (See appendix for codes)
                FORMAT:  I3
            DATA TYPE:  I*2

R4.     HTSI     , Height Site Index Tree
                   (feet)
                FORMAT:  I3
            DATA TYPE:  I*2

R5.     AGESI    , Total Age Site Index Tree
                   (years)
                FORMAT:  I3
            DATA TYPE:  I*2

R6.     YRSADD   , Years Added to DBH Age for Total Age
                FORMAT:  I2
            DATA TYPE:  I*2
```

RECORD 7 (POINT) DEFINITION ***

Record type 7 (POINT) contains data tallied for nonstocked points on forest plots.

```
MAXIMUM RECS/CASE:   10
CASE IDENTIFIER:     IDENT (A)

SORT IDENTIFIER: (1) PTNUM (A)

C6.     IDENT    , Case Identifier
                   (Unit & Seq.Plot Num.)
                 FORMAT:  I6
              DATA TYPE:  I*4

R1.     PTNUM    , Point Number
                 FORMAT:  I4
              DATA TYPE:  I*2

R2.     PTCLS    , Point Class
                 FORMAT:  I2
              DATA TYPE:  I*2
           VALUE LABELS:  (50) Inhibiting Vegetation
                          (51) Inhib. Veg.-Grass
                          (52) Inhib. Veg.-Shrubs
                          (53) Inhib. Veg.-Vines
                          (54) Inhib. Veg.-Other
                          (60) Nonstocked
                          (70) Overtopped
                          (80) Nonstockable
                          (81) Nonstockable-Rocks
                          (82) Nonstockable-Water
                          (83) Nonstockable-Other
```

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SECTION III.--STORED PROCEDURES

The Procedure File is a part of a SIR data base. "This file contains members which may be texts of commands, data or anything a user wishes to store with the data base. Typically, these texts will be frequently used SIR retrieval programs or other SIR command sequences.

"Each member in the Procedure File is identified by a member name and, optionally, a family name. Members are said to belong to a family and must have a unique name within the family." (Robinson et al. 1980).

We have created three families of procedures that we believe will be useful to users: COEF, LABEL, and VOLUME. Family COEF contains the coefficients needed to compute gross and net volumes using the equations presented by Hahn 1984, Smith and Weist 1982, Hahn 1976, Hahn 1975. Family LABEL contains procedures useful in making tables indexed by various dat items. Family VOLUME contains the procedures for computing volumes in board feet, cubic fee or green tons.

Procedure	
COEF.BDFT:T	
COEF.CUFT:T	
COEF.CUSL:T	
COEF.GRTONS:T	
COEF.HEIGHT:T	
VOLUME.BDFT20:T	These volume procedures compute the gross and net
VOLUME.BDFT31:T	cubic or board foot volume for the indicated tree
VOLUME.CUFT20:T	class from the tree d.b.h., top diameter outside bark
VOLUME.CUFT30:T	and species group. They are implemented by
VOLUME.CUFT40:T	CALL VOLUME.xxxxxx(Dbh,tdob,sp.gp.)
VOLUME.GRTONS:T	Computes biomass in green tons.
VOLUME.HEIGHT:T	Computes total or merchantable height.

Procedure	Description
LABEL.BACLASS:T	Computes an index and labels in variable BACLS for stand basal area using the variable BACUR.
LABEL.CONUNS:T	Computes an index and labels in variable CONUN for conifer understory using the variable CUNCOND.
LABEL.DBHCLS:T	Computes an index and labels in variables DIACLS1, DIACLS5, and DIACLS9 for 2-inch diameter class using the variable DBHCUR.
LABEL.DEATH:T	Computes an index and labels in variable DEATH for cause of death using the variable DAMDETH.
LABEL.LANDCLS:T	Computes an index and labels in variable LANDUSE for ground land use using the variables GLUCUR and FORTCUR.
LABEL.LIVE:T	Computes an index and labels in variable LIVE for tree history of live trees using the variable TRHISTCU.
LABEL.LOGGRD:T	Computes an index and labels in variable LOGGRD for tree log grade using the variable LOGGR.
LABEL.OWNER:T	Computes an index and labels in variable OWNER for stand owner class using the variable OWNGP.
LABEL.SICLS:T	Computes an index and labels in variable SICLS for stand site index using the variable SITEIND.
LABEL.SPECIES:T	Computes an index and labels in variables SPECIEC and SPECIESN for individual tree species of commercial and noncommercial species, respectively, using the variable SPECIES.
LABEL.STCLGR:T	Computes an index and labels in variable BACLS for stand basal area using the variable BACUR.
LABEL.STDAGE:T	Computes an index and labels in variable STDAGECL for stand age using the variable STDAGE.
LABEL.STDVOL:T	Computes an index and labels in variable STDVOLCL for stand volume class using the variables GSCUVS and GSCUVH.
LABEL.SWDHWD:T	Computes an index and labels in variable SWDHWD for major tree species group using the variable SPECIES.
LABEL.TRCLASS:T	Computes an index and labels in variable TRCLASS for tree class using the variable TRCLS.

LABEL.TYPESZ:T	Computes an index and labels in variables FORTYPE and SZCLS for forest type and stand size class, respectively, using the variables FORTCUR and SZDNCUR.
LABEL.U1COUNTY:T LABEL.U2COUNTY:T LABEL.U3COUNTY:T LABEL.U4COUNTY:T LABEL.U5COUNTY:T	These procedures compute an index and labels in variable COUNTY for county code using the variable UNTCO.

SECTION IV.--EXAMPLE RETRIEVALS

The following is a simple retrieval that will produce a table of area of commercial forest land by ownership group and forest type for a five-county area in central Wisconsin. The submit file shown below has two main parts, the Cyber control statements and the SIR retrieval statements. The Cyber control statements are the first part of the file, up through "/EOR" statement. These statements identify the user number, set time limits, execute SIR, save output files, and send the output files to the printer. This part of the submit file will be basically the same for all retrievals. For information on these commands, see the University of Minnesota Computer Center User's Manual. The remainder of the submit file contains SIR retrieval statements that are used to retrieve the needed data and construct the output table. This part of the submit file will be different for every retrieval. For information on these commands, see the SIR Version 2 User's Manual and SIR/DBMS TABLE Procedure Reference Guide.

****

```
/JOB
/NOSEQ
MHH,T20.
/USER
FETCH,SIR.
SIR.
RETAIN,EXAM1TB.
GOFO,COST.
EXIT.
COST.
DAYFILE.
RETAIN,OUTPUT=EXAM1OT.
ROUTE,OUTPUT,DC=PR,TID=BC,BIN=R69,EC=A9.
ROUTE,EXAM1OT,DC=PR,TID=BC,BIN=R69,EC=A9.
/EOR
OLD FILE        WISSOU
PASSWORD        WISSOU
SECURITY        WISSOU,WISSOU
PAGESIZE        63,89
RETRIEVAL
PROCESS CASE    LIST = 300000 THRU 399999
INCLUDE         FORTYPE,OWNGP,EXPAREA


.  IF     (GLUCUR GT 22) NEXT CASE
.  IFNOT  (UNTCO EQ 301 OR 308 OR 310 OR 311 OR 312 ) NEXT CASE
.  PROCESS REC 2
.    MOVE VARS OWNGP,EXPAREA
.    CALL LABEL.TYPESZ
.  END PROCESS REC
.  PERFORM PROCS
END PROCESS CASE
TABLE FORTYPE.T, OWNGP.T BY EXPAREA.O/
      FILENAME=EXAM1TB/
      PAGELENGTH=63/PAGEWIDTH=89/HEADERWIDTH=12/
      STUBTITLE = 'Forest type'/
      WAFERTITLE =
    'Example 1.--Area of commercial forest land by ownership'
    'and forest type, Adams, Marquette, Portage, Waupaca, and'
    'Waushara counties, Wisconsin, 1983.'
    'North Central Forest Experiment Station FI&A Data Base.'
    '     '
    '(In acres)'/
      NOOVERPRINTING/NOBOLDPRINTING
END RETRIEVAL
FINISH
```

The following table was produced by this retrieval and retained in the file EXAM1TB.

****

/DBMS Table Procedure Page 1

Example 1.--Area of commercial forest land by ownership and forest type, Adams, Marquette, Portage, Waupaca, and Waushara counties, Wisconsin, 1983.

North Central Forest Experiment Station FI&A Data Base.

(In acres)

Forest type	TOTAL	National forest	Other public	Private
	Area expander		Area expander	
TOTAL...............	821100	0	31600	789500
Jack pine...........	51500	0	0	51500
Red pine............	85700	0	0	85700
White pine..........	25100	0	2300	22800
Balsam fir..........	7200	0	0	7200
White spruce........	0	0	0	0
Black spruce........	0	0	0	0
Northern white-cedar	13900	0	0	13900
Tamarack............	13700	0	0	13700
Oak-hickory.........	290300	0	11500	278800
Elm-ash-soft maple..	100400	0	2200	98200
Maple-birch.........	103400	0	4400	99000
Aspen...............	91100	0	11200	79900
Paper birch.........	18300	0	0	18300
Exotic..............	2200	0	0	2200
Nonstocked..........	18300	0	0	18300

The following listing was produced in example 1 and retained in the file EXAM1OT.

```
*************************************************************************************

 R / D B M S  2 . 1 . 1      (SIR/DBMS 2.1.1)    01/12/84  16:15:52  PAGE     1

            OLD FILE          WISSOU
            PASSWORD       XXXXXXXXXXXXXXX
            SECURITY       XXXXXXXXXXXXXXX
            PAGESIZE          63,89
            RETRIEVAL
            PROCESS CASE      LIST = 300000 THRU 399999
            INCLUDE           FORTYPE,OWNGP,EXPAREA
            .  IF     (GLUCUR GT 22) NEXT CASE
            .  IFNOT  (UNTCO EQ 301 OR 308 OR 310 OR 311 OR 312 ) NEXT CASE
            .  PROCESS REC 2
            .    MOVE VARS OWNGP,EXPAREA
            .    CALL LABEL.TYPESZ
            .    RECODE       FORTYPE=FORTCUR(1=1)(2=2)(3=3)(6=14)(13=4)(12=6)
                                             (16=5)(14=7)(15=8)(50=9)(70=10)
                                             (80=11)(91=12)(92=13)
            .    IF           (SZDNCUR EQ 40) FORTYPE = 15
            .    COMPUTE      STDSZCLS = TRUNC(SZDNCUR/10)
            .    VAR RANGES   STDSZCLS(1,4)/
                              FORTYPE(1,15)
            .    VAR LABELS   STDSZCLS Stand size class/
                              FORTYPE  Forest type
            .    VALUE LABELS STDSZCLS (1) Sawtimber
                                       (2) Poletimber
                                       (3) Sapling & seedling
                                       (4) Nonstocked/
                              FORTYPE  (1) Jack pine
                                       (2) Red pine
                                       (3) White pine
                                       (4) Balsam fir
                                       (5) White spruce
                                       (6) Black spruce
                                       (7) Northern white-cedar
                                       (8) Tamarack
                                       (9) Oak-hickory
                                       (10) Elm-ash-soft maple
                                       (11) Maple-birch
                                       (12) Aspen
                                       (13) Paper birch
                                       (14) Exotic
                                       (15) Nonstocked
            .  END PROCESS REC
            .  PERFORM PROCS
            END PROCESS CASE
            TABLE FORTYPE.T, OWNGP.T BY EXPAREA.O/

                  FILENAME=EXAM1TB/
                  PAGELENGTH=63/PAGEWIDTH=89/HEADERWIDTH=12/
                  STUBTITLE = 'Forest type'/
                  WAFERTITLE =
                'Example 1.--Area of commercial forest land by ownership'
                'and forest type, Adams, Marquette, Portage, Waupaca, and'
                'Waushara counties, Wisconsin, 1983.'
                'North Central Forest Experiment Station FI&A Data Base.'
                '     '
                '(In acres)'/
                  NOOVERPRINTING/NOBOLDPRINTING
            END RETRIEVAL
            FINISH
```

```
FULL  DAYFILE.  84/01/12. 16.19.19.* AKZIBDK* PAGE     1

 AKZIBDK. 84/01/12.UOFM CYBER A (01/02-BO).
16.15.44.MHH,T20.
16.15.44.$USER(WXL6007,)
16.15.44. FAMILY PARAMETER MISSING.  FAMILY CA ASSUMED.
16.15.46.FETCH,SIR.
16.15.52.SIR.
16.15.53.*** REMARK ***  BEGIN SIR/DBMS 2.1.1 RUN.
16.15.55.*** REMARK ***  TASK TABLE SPACE USED:     126
16.15.55.*** REMARK ***  TOTAL CPU TIME USED (MS): 37
16.15.56.*** REMARK ***   START RETRIEVAL TRANSLATION.
16.16.05.*** REMARK ***   START RETRIEVAL EXECUTION.
16.19.17.*** REMARK ***   RETRIEVAL COMPLETE.
16.19.18.*** REMARK ***  TASK TABLE SPACE USED:    4355
16.19.18.*** REMARK ***  TOTAL CPU TIME USED (MS): 7845
16.19.18.*** REMARK ***  END SIR RUN:          0
16.19.18.*** REMARK ***  TOTAL CPU TIME (MS): 7855
16.19.18.*** REMARK ***  TABLE SPACE    USED: 4355
16.19.18.*** REMARK ***  FIELD LENGTH   USED: 36800
16.19.19.RETAIN,EXAM1TB.
16.19.19. EXAM1TB PURGED.
16.19.19. PERMANENT FILE EXAM1TB, 7 PRUS.
16.19.19.GOFO,COST.
16.19.19.COST.
16.19.19. ACCUMULATED JOB COST - UNIVERSITY RATE.
16.19.19. CP      7.906 SEC.
16.19.19. MS     57.732 KUN.
16.19.19. PF       .108 KUN.
16.19.19. CM     69.470 KWD.
16.19.19. SR     21.555 UNS.
16.19.19. CURRENT JOB COST =     $ 3.23
16.19.19.DAYFILE.

********************************************************************************
```

Example 1.

This is a simple retrieval that produces a commonly requested table for a specific area. The retrieval uses the PROCESS CASE command to restrict the retrieval to the desired forest survey unit. An IF statement is used to further restrict the retrieval to only commercial forest land and an IFNOT statement is used to restrict it to the desired five-county area. Becasuse the retrieval requires only data stored in record type 2 , only that record is accessed. Two of the variables required to construct the table (OWNGP and AREAEXP) are stored as needed in the data base and can be moved to the summary record with a MOVE VARS command. A stored procedure TYPESZ is called to compute FORTYPE from FORTCUR to reduce the space needed to produce the output table. The cost shown for this example is based on daytime rates for university or affiliated users. Higher rates are charged to private and corporate users; lower rates are charged for jobs submitted to be run in the evening or overnight.

Two more example retrievals follow. Although these retrievals are more complicated, they are basically extensions of the first example. Only the SIR retrieval statements section of the submit file are shown for these examples because the Cyber control statements do not differ.

Example 2.

This retrieval produces two different outputs, a table and a data file, for a single county. The table presents number of ground plots, area of commercial forest land, and average softwood and hardwood volume per acre by forest type. The data file contains two types of records: (1) a plot record that is identified by a 1 in the first column and (2) tree records that have a 2 in column one.

```
********************************************************************************

OLD FILE          WISSOU
PASSWORD          WISSOU
SECURITY          WISSOU,WISSOU
PAGESIZE          63,89
RETRIEVAL
PROCESS CASE      LIST = 300000 THRU 399999
INCLUDE           IDENT,FORTCUR,EXPAREA,OWNGP,SITEIND,
                  TRNUM,DBHCUR,TRHIST,NCSPGP,EXPANDR,GSCUVS,GSCUVH
  IFNOT  (UNTCO EQ 302) NEXT CASE
  IF     (GLUCUR GT 22) NEXT CASE
  PROCESS REC 2
    MOVE VARS IDENT,FORTCUR,OWNGP,SITEIND,GSCUVS,GSCUVH,EXPAREA
COMMENT ========== COMPUTE FOREST TYPE ====================
    CALL LABEL.TYPESZ
COMMENT ========== ROUND ACRES FOR TABLE ====================
    COMPUTE    MACRES = RND(EXPAREA/100)/10
    VAR LABEL  MACRES Area (Thousand acres)/
COMMENT ========== GENERATE A PLOT RECORD ====================
    WRITE       '1 ' IDENT (I6), UNTCO (I3), FORTCUR (I4), EXPAREA (I7),
                OWNGP (I3), SITEIND (I5)
  END PROCESS REC
  PROCESS REC   3
    MOVE VARS    IDENT,TRNUM,DBHCUR,TRHIST,NCSPGP,EXPANDR
COMMENT ========== GENERATE A TREE RECORD ====================
    WRITE       '2 ' IDENT (I6), TRNUM (I5), DBHCUR (F5.1), TRHIST (I3),
                 NCSPGP (I3), EXPANDR (I3)
  END PROCESS REC
  PERFORM PROCS
END PROCESS CASE
TABLE FORTYPE THEN TOTFT, N THEN MACRES.O THEN (GSCUVS THEN GSCUVH) BY MEAN/
     FILENAME=EXAM2TB/
     PRINTFORMAT = N(C,0) MACRES(C,1) CSUVS(C,0) GSCUVH(C,0)/
     TOTAL= N 'Number of plots' TOTFT 'All types'/
     MEAN = MEAN '(cubic feet per acre)'/
     PAGETITLE = 'Example 2.'/
         PAGELENGTH = 63/
     PAGEWIDTH = 89/
     HEADERDIVIDER = ' '/
     STUBDIVIDER = '-'/
     STUBFILLER = ' '/
     HEADERWIDTH = 12/
     STUBTITLE = 'Forest type'/
     WAFERTITLE =
     'Example 2.--Number of plots, area of commercial forest land,'
     'and average softwood and hardwood volume per acre,'
     'Chippewa County, Wisconsin, 1983'/
     NOLEFTBORDER/NORIGHTBORDER/
     NOZEROS/NOEMPTYROWS/
     NOOVERPRINTING/NOBOLDPRINTING
END RETRIEVAL
FINISH
```

The following table was produced by this retrieval and retained in the file EXAM2TB.

```
******************************************************************************
Example 2.                                                              Page 1
```

Example 2.--Number of plots, area of commercial forest land, and average softwood and hardwood volume per acre, Chippewa County, Wisconsin, 1983

Forest type	Number of plots	Area (Thousand acres)	Growing stock cubic foot volume softwood (cubic feet per acre)	Growing stock cubic foot volume hardwood (cubic feet per acre)
Jack pine	1	2.5	631	-
White pine	2	5.0	1496	148
Black spruce	1	2.4	72	-
Tamarack	3	7.3	520	263
Oak-hickory	11	27.1	87	1,071
Elm-ash-soft maple	16	39.4	15	596
Maple-birch	32	77.8	31	938
Aspen	19	47.0	34	1,040
Paper birch	6	14.7	114	749
Nonstocked	1	2.5	-	133
All types	92	225.7	95	835

The following listing was produced in example 2 and retained in the file EXAM2OT. The data file was written by the two WRITE statements and is part of this output file. Only a portion of the data file is shown.

```
******************************************************************************

S I R / D B M S  2 . 1 . 1        (SIR/DBMS 2.1.1)       01/23/84  16:25:07  PAGE    1

          OLD FILE          WISSOU
          PASSWORD       XXXXXXXXXXXXXXX
          SECURITY       XXXXXXXXXXXXXXX
          PAGESIZE          63,89
          RETRIEVAL
          PROCESS CASE      LIST = 300000 THRU 399999
          INCLUDE           IDENT,FORTCUR,EXPAREA,OWNGP,SITEIND,
                            TRNUM,DBHCUR,TRHIST,NCSPGP,EXPANDR,GSCUVS,GSCUVH
          . IFNOT  (UNTCO EQ 302) NEXT CASE
          . IF     (GLUCUR GT 22) NEXT CASE
          . PROCESS REC 2
          .   MOVE VARS IDENT,FORTCUR,OWNGP,SITEIND,GSCUVS,GSCUVH,EXPAREA
          COMMENT ========= COMPUTE FOREST TYPE ==================
          .   CALL LABEL.TYPESZ
                .   CALL LABEL.TYPESZ
     .    RECODE       FORTYPE=FORTCUR(1=1)(2=2)(3=3)(6=14)(13=4)(12=6)
                                  (16=5)(14=7)(15=8)(50=9)(70=10)
                                  (80=11)(91=12)(92=13)
     .    IF           (SZDNCUR EQ 40) FORTYPE = 15
     .    COMPUTE      STDSZCLS = TRUNC(SZDNCUR/10)
     .    VAR RANGES   STDSZCLS(1,4)/
                       FORTYPE(1,15)
     .    VAR LABELS   STDSZCLS Stand size class/
                       FORTYPE  Forest type
     .    VALUE LABELS STDSZCLS (1) Sawtimber
                                (2) Poletimber
```

```
                             (3) Sapling & seedling
                             (4) Nonstocked/
                  FORTYPE    (1) Jack pine
                             (2) Red pine
                             (3) White pine
                             (4) Balsam fir
                             (5) White spruce
                             (6) Black spruce
                             (7) Northern white-cedar
                             (8) Tamarack
                             (9) Oak-hickory
                             (10) Elm-ash-soft maple
                             (11) Maple-birch
                             (12) Aspen
                             (13) Paper birch
                             (14) Exotic
                             (15) Nonstocked

      COMMENT ========== ROUND ACRES FOR TABLE ====================
      .    COMPUTE    MACRES = RND(EXPAREA/100)/10
      .    VAR LABEL  MACRES Area (Thousand acres)/
      COMMENT ========== GENERATE A PLOT RECORD ====================
      .    WRITE       '1 ' IDENT (I6), UNTCO (I3), FORTCUR (I4), EXPAREA (I7),
                       OWNGP (I3), SITEIND (I5)
      .  END PROCESS REC
      .  PROCESS REC   3
      .    MOVE VARS    IDENT,TRNUM,DBHCUR,TRHIST,NCSPGP,EXPANDR
      COMMENT ========== GENERATE A TREE RECORD ====================
      .    WRITE       '2 ' IDENT (I6), TRNUM (I5), DBHCUR (F5.1), TRHIST (I3),
                        NCSPGP (I3), EXPANDR (I3)
      .  END PROCESS REC
      .  PERFORM PROCS
      END PROCESS CASE

      TABLE FORTYPE THEN TOTFT, N THEN MACRES.O THEN (GSCUVS THEN GSCUVH) BY MEAN/
            FILENAME=EXAM2TB/
            PRINTFORMAT = N(C,0) MACRES(C,1) CSUVS(C,0) GSCUVH(C,0)/
            TOTAL= N 'Number of plots' TOTFT 'All types'/
            MEAN = MEAN '(cubic feet per acre)'/
            PAGETITLE = 'Example 2.'/
            PAGELENGTH = 63/
            PAGEWIDTH = 89/
            HEADERDIVIDER = ' '/
            STUBDIVIDER = '-'/
            STUBFILLER = ' '/
            HEADERWIDTH = 12/
            STUBTITLE = 'Forest type'/
            WAFERTITLE =
            'Example 2.--Number of plots, area of commercial forest land,'
            'and average softwood and hardwood volume per acre,'
            'Chippewa County, Wisconsin, 1983'/
            NOLEFTBORDER/NORIGHTBORDER/
            NOZEROS/NOEMPTYROWS/
            NOOVERPRINTING/NOBOLDPRINTING
      END RETRIEVAL
1 300197302  50    2500  4   84
2 300197   101   6.0  1 20 19
2 300197   102   4.3  1 20100
2 300197   201  13.3  1 38  4
2 300197   202   7.3  1 21 13
2 300197   203   6.0  1 18 19
2 300197   301  13.9  1 38  4
2 300197   302   9.1  1 21  8
2 300197   401   1.5  2 50  0
2 300197   402   1.7  2 50  0
         .
         .
         .
1 354220302  91   2400  4   64
```

```
 2 354220  101  0.0 31 38100
 2 354220  102  0.0 31 38100
 2 354220  201  1.0 31 38100
 2 354220  301  0.0 31 38100
 2 354220  302  0.0 31 38100
 2 354220  303  0.0 31 38100
 2 354220  401  0.0 31 38  0
 2 354220  402  2.2 31 38  0
 2 354220  601  1.6 61 38  0
 2 354220  701  0.0 31 38  0
 2 354220  702  0.0 31 38  0
 2 354220  703  0.0 31 38  0
 2 354220  704  0.0 31 38  0
 2 354220  705  0.0 31 38  0
 2 354220  706  0.0 31 38  0
 2 354220  707  0.0 31 38  0
 2 354220  801  1.7 61 38  0
 2 354220  901  0.0 31 39  0
 2 354220  902  0.0 31 28  0
 2 354220  903  0.0 31 28  0
            FINISH
```

```
*******************************************************************************
```

This example was run at normal rates, used 10.995 seconds of central processing time, and cost $4.21 at university rates.

Example 3.

The following retrieval extracts the data for all plots located in a geographic area defined as a circle or a convex polygon, using Universal Transverse Mercator (UTM) coordinates. This retrieval also demonstrates the use of arrays, a FOR loop, and a WHILE loop to extract data for a pentagon-shaped area in the Upper Peninsula of Michigan. Only the retrieval is shown; any appropriate tables could be constructed using the selected plots and the previously described TABLE procedures.

```
*************************************************************************
OLD FILE          MICHUP
PASSWORD          MICHUP
SECURITY          MICHUP,MICHUP
PAGESIZE          58,136
RETRIEVAL
CALL COEF.HEIGHT
CALL COEF.CUFT
.  EXCLUDE        C2A1 TO C2A50,C2B1 TO C2B50,C2C1 TO C2C50,C3C1 TO C3C50,
                  C4C1 TO C4C50,HTA1 TO HTA50,HTB1 TO HTB50,HTC1 TO HTC50,
                  HTD1 TO HTD50,HTE1 TO HTE50,HTF1 TO HTF50
COMMENT Procedure to determine if a given UTM location is within

            a specified circle or convex polygon. The following

            variables are used.

            NCORNER = The number of sides(corners/vertices) of the

                      polygon. If NCORNER = 1 a circle is assumed.

                      If NCORNER = 0 a county retrieval is assumed.
```

```
          NZONE   = The UTM zone for the supplied coordinates.
          XCORD1 TO XCORD10 = Up to 10 values for the EASTING

                    coordinate of each of the verticies.
          YCORD1 TO YCORD10 = Up to 10 values for the NORTHING

                    coordinate of each of the verticies.
          If NCORNER = 1 XCORD1, YCORD1 is the coordinate of

                       the center of the circle.
             NCORNER = 0 XCORD contains Unit,County(UNTCO) codes

                       for counties to be retrieved and RADIUS

                       contains the number of counties to be retrieved.

          RADIUS = Radius of the circle in kilometers for a circle

                   retrieval or the number of counties for a county

                   retrieval.

.  SET              NCORNER,RADIUS,XCORD1 TO XCORD10,YCORD1 TO YCORD10,
                    XMAX,XMIN,YMAX,YMIN,XT1 TO XT3,YT1 TO YT3,A1 TO A3,
                    B1 TO B3,V1 TO V3(0)
COMMENT Enter data to define search area.
.  COMPUTE          NCORNER = 5;
                    RADIUS = 80;
                    NZONE = 16
COMMENT Enter coordinates of verticies XCORD are Easting and
        YCORD are northing.
.  COMPUTE          XCORD1 =  323;YCORD1 = 5194;
                    XCORD2 =  350;YCORD2 = 5160;
                    XCORD3 =  330;YCORD3 = 5101;
                    XCORD4 =  200;YCORD4 = 5140;
                    XCORD5 =  290;YCORD5 = 5180;
                    XCORD6 =    0;YCORD6 =    0;
                    XCORD7 =    0;YCORD7 =    0;
                    XCORD8 =    0;YCORD8 =    0;
                    XCORD9 =    0;YCORD9 =    0;
                    XCORD10=    0;YCORD10=    0
.  IFTHEN           (NCORNER GE 3)
COMMENT Define square containing subject polygon.
.    COMPUTE        XMAX = XCORD1; YMAX = YCORD1;
                    XMIN = XCORD1; YMIN = YCORD1
.    FOR            I = 2,NCORNER
.      COMPUTE      XTEST = XCORD1 TO XCORD10(I);
                    YTEST = YCORD1 TO YCORD10(I)
.      IF           (XTEST GT XMAX) XMAX = XTEST
.      IF           (XTEST LT XMIN) XMIN = XTEST
.      IF           (YTEST GT YMAX) YMAX = YTEST
.      IF           (YTEST LT YMIN) YMIN = YTEST
.    END FOR
.  ELSE
.  ENDIF
SET                 NPLTS,NTRS,NSUM(0)
PROCESS CASES       SAMPLE=.20,31
COMMENT Select commercial forest plots only.
.  IFNOT            (GLUCUR LE 29) NEXT CASE
.  PROCESS REC      1
.    COMPUTE        UTME=UTMEAST;UTMN=UTMNORTH
.    MOVE VARS      UNTCO
COMMENT OUT = 1 is true; 0 is false.
.    IFTHEN         (NCORNER EQ 0)
```

```
COMMENT Search is a county retrieval.
.       COMPUTE      OUT = 1
.       FOR          I = 1,RADIUS
.         IF         (UNTCO EQ XCORD1 TO XCORD10(I)) OUT = 0
.       END FOR
.     ELSEIF         (NCORNER EQ 1)
COMMENT Search area is a circle.
    Correct easting for zone change. 460 kilometers used for
        northern Michigan and Wisconsin.
.       IFTHEN       (UTMZONE NE NZONE)
.         IFTHEN     (UTMZONE LT NZONE)
.           COMPUTE UTME = UTME - 460
.         ELSE
.           COMPUTE UTME = UTME + 460
.         ENDIF
.       ELSE
.       ENDIF
.       COMPUTE      OUT = 1
.       COMPUTE      DISTANCE = (UTME-XCORD1)**2 + (UTMN-YCORD1)**2
.       IF           ((RADIUS - DISTANCE) GE 0.0) OUT = 0
.     ELSE
COMMENT Search area is a polygon.
        Correct easting for zone change. 460 kilometers used for
        northern Michigan and Wisconsin.
.       IFTHEN       (UTMZONE NE NZONE)
.         IFTHEN     (UTMZONE LT NZONE)
.           COMPUTE UTME = UTME - 460
.         ELSE
.           COMPUTE UTME = UTME + 460
.         ENDIF
.       ELSE
.       ENDIF
.       IFTHEN       (UTME GT XMAX OR UTME LT XMIN OR
                      UTMN GT YMAX OR UTMN LT YMIN)
.         COMPUTE    OUT = 1
.       ELSE
.         COMPUTE    OUT = 1;
                     ICOUNT = 0;
                     NCORNERT = NCORNER-2
.         WHILE      (ICOUNT LT NCORNERT AND OUT EQ 1)
.           COMPUTE ICOUNT = ICOUNT + 1;
                     ICOUN1 = ICOUNT + 1;
                     ICOUN2 = ICOUNT + 2;
                     XT1 = XCORD1;
                     XT2 = XCORD1 TO XCORD10(ICOUN1);
                     XT3 = XCORD1 TO XCORD10(ICOUN2);
                     YT1 = YCORD1;
                     YT2 = YCORD1 TO YCORD10(ICOUN1);
                     YT3 = YCORD1 TO YCORD10(ICOUN2);
                     A1 = (YT3-YT2) / (XT2*YT3 - XT3*YT2);
                     A2 = (YT3-YT1) / (XT1*YT3 - XT3*YT1);
                     A3 = (YT2-YT1) / (XT1*YT2 - XT2*YT1);
                         B1 = (XT3-XT2) / (XT2*YT3 - XT3*YT2);
                     B2 = (XT3-XT1) / (XT1*YT3 - XT3*YT1);
                     B3 = (XT2-XT1) / (XT1*YT2 - XT2*YT1);
                     V1 = (A1*UTME + B1*UTMN - 1.0) *
                          (A1*XT1 + B1*YT1 - 1.0);
                     V2 = (A2*UTME + B2*UTMN - 1.0) *
                          (A2*XT2 + B2*YT2 - 1.0);
                     V3 = (A3*UTME + B3*UTMN - 1.0) *
                         (A3*XT3 + B3*YT3 - 1.0)
.           IF       (V1 GE 0.0 AND V2 GE 0.0 AND V3 GE 0.0) OUT = 0
.         END WHILE
.       ENDIF
.     ENDIF
COMMENT If plot is not in specified region reject case.
.     IFNOT          (OUT EQ 0) NEXT CASE
.   END PROCESS REC
.   PROCESS REC      2
.     MOVE VARS      BACUR,SITEIND
```

```
.  END PROCESS REC
.  PROCESS REC      3
.    COMPUTE        STATUS = MOD(TRHIST,10)
COMMENT Select live trees only
.    IFNOT          (STATUS LE 2) NEXT REC
COMMENT Select pole sized and larger trees only
.    IFNOT          (TRSZCLS GE 2) NEXT REC
.    COMPUTE        NTRS = NTRS + 1
.    IFTHEN         (TRCLS LE 20)
.      COMPUTE      CUFTORG = 0.0
CALL VOLUME.CUFT20(DBHORG,4.0,NCSPGP)
.      COMPUTE      CUFTORG = CUFTNET
CALL VOLUME.CUFT20(DBHCUR,4.0,NCSPGP)
COMMENT Compute net growth
.      COMPUTE      NETGRO = ((CUFTNET-CUFTORG)*EXPANDR-CUFTNET*MORTFAC)*EXPAREA
.    ELSEIF         (TRCLS EQ 40)
CALL VOLUME.CUFT40(DBHCUR,4.0,NCSPGP)
.    ELSE
CALL VOLUME.CUFT30(DBHCUR,4.0,NCSPGP)
.    ENDIF
COMMENT Compute number of trees
.    COMPUTE        NUMTRS = EXPANDR*EXPAREA
COMMENT Compute cubic foot volume
.    COMPUTE        NETVOL = CUFTNET*EXPANDR*EXPAREA
.    COMPUTE        NSUM = NSUM + 1
.    PERFORM PROCS
.  END PROCESS REC
END PROCESS CASES
BLANK LINES     10
COMMENT List records processed in retrieval
WRITE 10X'PLOTS PROCESSED = ',NPLTS/10X,'TREES PROCESSED = ',NTRS
     /10X'SUMMARY RECORDS = ',NSUM
```

APPENDIX A.--DEFINITION OF CODES

Codes for variable C1 UNTCO

State = Michigan   State code = 26
Data base number and name (I) MICHUP

Code	County name	Code	County name	Code	County name	Code	County name
Eastern Upper Peninsula							
(101)	Alger	(102)	Chippewa	(103)	Delta	(104)	Luce
(105)	Mackinac	(106)	Menominee	(107)	Schoolcraft		
Western Upper Peninsula							
(201)	Baraga	(202)	Dickinson	(203)	Gogebic	(204)	Houghton
(205)	Iron	(206)	Keweenaw	(207)	Marquette	(208)	Ontonagon

Data base number and name (II) MICHLP

Code	County name	Code	County name	Code	County name	Code	County name
Northern Lower Peninsula							
(301)	Alcona	(302)	Alpena	(303)	Antrim	(304)	Arenac
(305)	Bay	(306)	Benzie	(307)	Charlevoix	(308)	Cheboygan
(309)	Clare	(310)	Crawford	(311)	Emmet	(312)	Gladwin
(313)	Grand Traverse	(314)	Iosco	(315)	Isabella	(316)	Kalkaska
(317)	Lake	(318)	Leelanau	(319)	Manistee	(320)	Mason
(321)	Mecosta	(322)	Midland	(323)	Missaukee	(324)	Montmorency
(325)	Newaygo	(326)	Oceana	(327)	Ogemaw	(328)	Osceola
(329)	Oscoda	(330)	Otsego	(331)	Presque Isle	(332)	Roscommon
(333)	Wexford						
Southern Lower Peninsula							
(401)	Allegan	(402)	Barry	(403)	Berrien	(404)	Branch
(405)	Calhoun	(406)	Cass	(407)	Clinton	(408)	Eaton
(409)	Genesee	(410)	Gratiot	(411)	Hillsdale	(412)	Huron
(413)	Ingham	(414)	Ionia	(415)	Jackson	(416)	Kalamazoo
(417)	Kent	(418)	Lapeer	(419)	Lenawee	(420)	Livingston
(421)	Macomb	(422)	Monroe	(423)	Montcalm	(424)	Muskegon
(425)	Oakland	(426)	Ottawa	(427)	Saginaw	(428)	St. Clair
(429)	St. Joseph	(430)	Sanilac	(431)	Shiawassee	(432)	Tuscola
(433)	Van Buren	(434)	Washtenaw	(435)	Wayne		

State = Wisconsin   State code = 55
Data base number and name (III) WISNOR

Code	County name	Code	County name	Code	County name	Code	County name
Northeast Unit							
(101)	Florence	(102)	Forest	(103)	Langlade	(104)	Lincoln
(105)	Menominee	(106)	Marinatte	(107)	Oconto	(108)	Oneida
(109)	Shawano	(110)	Vilas				
Northwest Unit							
(201)	Ashland	(202)	Barron	(203)	Bayfield	(204)	Burnett
(205)	Douglas	(206)	Iron	(207)	Polk	(208)	Price
(209)	Rusk	(210)	Sawyer	(211)	Taylor	(212)	Washburn

Code	County name	Code	County name	Code	County name	Code	County name
Data base number and name (IV) WISSOU							
Central Unit							
(301)	Adams	(302)	Chippewa	(303)	Clark	(304)	Eau Claire
(305)	Jackson	(306)	Juneau	(307)	Marathon	(308)	Marquette
(309)	Monroe	(310)	Portage	(311)	Waupaca	(312)	Waushara
(313)	Wood						
Southwest Unit							
(401)	Buffalo	(402)	Crawford	(403)	Dunn	(404)	Grant
(405)	Iowa	(406)	La Crosse	(407)	Lafayette	(408)	Pepin
(409)	Pierce	(410)	Richland	(411)	St. Croix	(412)	Sauk
(413)	Tempeleau	(414)	Vernon				
Southeast Unit							
(501)	Brown	(502)	Calumet	(503)	Columbia	(504)	Dane
(505)	Dodge	(506)	Door	(507)	Fond du Lac	(508)	Green
(509)	Green Lake	(510)	Jefferson	(511)	Kenosha	(512)	Kewaunee
(513)	Manitowoc	(514)	Milwaukee	(515)	Outagamie	(516)	Ozaukee
(517)	Racine	(518)	Rock	(519)	Sheboygen	(520)	Walworth
(521)	Washington	(522)	Waukesha	(523)	Winnebago		
State = Minnesota State code = 27							
Data base number and name (V) MINNOR							
Aspen-Birch Unit							
(101)	Carlton	(102)	Cook	(103)	Koochiching	(104)	Lake
(105)	St. Louis						
Northern Pine Unit							
(201)	Aitkin	(202)	Becker	(203)	Beltrami	(204)	Cass
(205)	Clearwater	(206)	Crow Wing	(207)	Hubbard	(208)	Itasca
(209)	Lake of the Woods			(210)	Mahnomen	(211)	Roseau
(212)	Wadena						
Data base number and name (VI) MINSOU							
Central Hardwood Unit							
(301)	Anoka	(302)	Benton	(303)	Carver	(304)	Chisago
(305)	Dakota	(306)	Douglas	(307)	Fillmore	(308)	Goodhue
(309)	Hennepin	(310)	Houston	(311)	Isanti	(312)	Kanabec
(313)	Le Sueur	(314)	Mille Lacs	(315)	Morrison	(316)	Olmsted
(317)	Otter tail	(318)	Pine	(319)	Ramsey	(320)	Rice
(321)	Scott	(322)	Sherburne	(323)	Stearns	(324)	Todd
(325)	Wabasha	(326)	Washington	(327)	Winona	(328)	Wright
Prairie Unit							
(401)	Big Stone	(402)	Blue Earth	(403)	Brown	(404)	Chippewa
(405)	Clay	(406)	Cottonwood	(407)	Dodge	(408)	Fairbault
(409)	Freeborn	(410)	Grant	(411)	Jackson	(412)	Kandiyohi
(413)	Kittson	(414)	Lac qui Parle	(415)	Lincoln	(416)	Lyon
(417)	McLeod	(418)	Marshall	(419)	Martin	(420)	Meeker
(421)	Mower	(422)	Murray	(423)	Nicollet	(424)	Nobles
(425)	Norman	(426)	Pennington	(427)	Pipestone	(428)	Polk
(429)	Pope	(430)	Red Lake	(431)	Redwood	(432)	Renville
(433)	Rock	(434)	Sibley	(435)	Steele	(436)	Stevens
(437)	Swift	(438)	Traverse	(439)	Waseca	(440)	Watonwan
(441)	Wilkin	(442)	Yellow Medicine				

Code	County name	Code	County name	Code	County name	Code	County name

State = North Dakota   State code = 38
Data base number and name (VII) NDAKOTA

(101) Adams	(102) Barnes	(103) Benson	(104) Billings
(105) Bottineau	(106) Bowman	(107) Burke	(108) Burleigh
(109) Cass	(110) Cavalier	(111) Dickey	(112) Divide
(113) Dunn	(114) Eddy	(115) Emmons	(116) Foster
(117) Golden Valley	(118) Grand Forks	(119) Grant	(120) Griggs
(121) Hettinger	(122) Kidder	(123) LaMoure	(124) Logan
(125) McHenry	(126) McIntosh	(127) McKenzie	(128) McLean
(129) Mercer	(130) Morton	(131) Mountrail	(132) Nelson
(133) Oliver	(134) Pembina	(135) Pierce	(136) Ramsey
(137) Ransom	(138) Renville	(139) Richland	(140) Rolette
(141) Sargent	(142) Slope	(143) Sheridan	(144) Sioux
(145) Stark	(146) Steele	(147) Stutsman	(148) Towner
(149) Traill	(150) Walsh	(151) Ward	(152) Wells
(153) Williams			

State = South Dakota   State code = 46
Data base number and name (VIII) SDAKOTA

Eastern Unit

(101) Aurora	(102) Beadle	(103) Bennet	(104) Bon Homme
(105) Brookings	(106) Brown	(107) Brule	(108) Buffalo
(109) Campbell	(110) Charles	(111) Clark	(112) Clay
(113) Codington	(114) Corson	(115) Custer	(116) Davison
(117) Day	(118) Deuel	(119) Dewey	(120) Douglas
(121) Edmunds	(122) Faulk	(123) Grant	(124) Gregory
(125) Haakon	(126) Hamlin	(127) Hand	(128) Hanson
(129) Hughes	(130) Hutchinson	(131) Hyde	(132) Jackson
(133) Jerauld	(134) Jones	(135) Kingsbury	(136) Lake
(137) Lincoln	(138) Lyman	(139) Marshall	(140) McCook
(141) McPherson	(142) Mead	(143) Mellette	(144) Miner
(145) Minnehaha	(146) Woody	(147) Pennington	(148) Perkins
(149) Potter	(150) Roberts	(151) Sanborn	(152) Shannon
(153) Spink	(154) Stanley	(155) Sully	(156) Todd
(157) Tripp	(158) Turner	(159) Union	(160) Walworth
(161) Washabaugh	(162) Yankton	(163) Ziebach	

Code	County name	Code	County name	Code	County name	Code	County name

State = Nebraska State code = 31
Data base number and name (IX) NEBRASK

Eastern Unit

(101) Adams	(102) Boone	(103) Buffalo	(104) Burt
(105) Butler	(106) Cass	(107) Cedar	(108) Clay
(109) Colfax	(110) Cuming	(111) Custer	(112) Dakota
(113) Dawson	(114) Dixon	(115) Dodge	(116) Douglas
(117) Fillmore	(118) Franklin	(119) Frontier	(120) Furnas
(121) Gage	(122) Gosper	(123) Greeley	(124) Hall
(125) Hamilton	(126) Harlan	(127) Hitchcock	(128) Howard
(129) Jefferson	(130) Johnson	(131) Kearney	(132) Lancaster
(133) Madison	(134) Merrick	(135) Nance	(136) Nemaha
(137) Nuckolls	(138) Otoe	(139) Pawnee	(140) Phelps
(141) Pierce	(142) Platte	(143) Polk	(144) Red Willow
(145) Richardson	(146) Saline	(147) Sarpy	(148) Saunders
(149) Seward	(150) Sherman	(151) Stanton	(152) Thayer
(153) Thurston	(154) Valley	(155) Washington	(156) Wayne
(157) Webster	(158) York		

Western Unit

(201) Antelope	(202) Arthur	(203) Banner	(204) Blaine
(205) Box Butte	(206) Boyd	(207) Brown	(208) Chase
(209) Cherry	(210) Cheyenne	(211) Dawes	(212) Deuel
(213) Dundy	(214) Garden	(215) Garfield	(216) Grant
(217) Hayes	(218) Holt	(219) Hooker	(220) Keith
(221) Keya Paha	(222) Kimball	(223) Knox	(224) Lincoln
(225) Logan	(226) Loup	(227) McPherson	(228) Morrill
(229) Perkins	(230) Rock	(231) Scotts Bluff	(232) Sheridan
(233) Sioux	(234) Thomas	(235) Wheeler	

Data base number and name (XI) IOWA

Northeast Unit

(101) Allamakee	(102) Benton	(103) Black Hawk	(104) Bremer
(105) Buchanan	(106) Butler	(107) Cedar	(108) Chicksaw
(109) Clayton	(110) Clinton	(111) Delaware	(112) Dubuque
(113) Fayette	(114) Floyd	(115) Grundy	(116) Howard
(117) Jackson	(118) Johnson	(119) Jones	(120) Linn
(121) Mitchell	(122) Scott	(123) Tama	(124) Winneshiek

Southeast Unit

(201) Appanoose	(202) Boone	(203) Clark	(204) Dallas
(205) Davis	(206) Decatur	(207) Des Moines	(208) Guthrie
(209) Hamilton	(210) Hardin	(211) Henry	(212) Iowa
(213) Jasper	(214) Jefferson	(215) Keokuk	(216) Lee
(217) Louisa	(218) Lucas	(219) Madison	(220) Mahaska
(221) Marion	(222) Marshall	(223) Monroe	(224) Muscatine
(225) Polk	(226) Poweshiek	(227) Story	(228) Van Buren
(229) Wapello	(230) Warren	(231) Washington	(232) Wayne
(233) Webster			

Southwest Unit

(301) Adair	(302) Adams	(303) Audubon	(304) Carroll
(305) Cass	(306) Crawford	(307) Fremont	(308) Greene
(309) Harrison	(310) Mills	(311) Monona	(312) Montgomery
(313) Page	(314) Pottawattami	(315) Ringgold	(316) Shelby
(317) Taylor	(318) Union	(319) Woodbury	

Northwest Unit

(401) Buena Vista	(402) Calhoun	(403) Cerro Sordo	(404) Cherokee
(405) Clay	(406) Dickinson	(407) Emmet	(408) Franklin
(409) Hancock	(410) Humboldt	(411) Ida	(412) Kossuth
(413) Lyon	(414) O'Brien	(415) Osceola	(416) Palo Alto
(417) Plymouth	(418) Pocahontas	(419) Sac	(420) Sioux
(421) Winnebago	(422) Worth	(423) Wright	

Code	County name	Code	County name	Code	County name	Code	County name

State = Missouri   State code = 29
Data base number and name (XII) MOZARK

Eastern Ozarks Unit

(101) Bollinger	(102) Butler	(103) Carter	(104) Crawford
(105) Dent	(106) Iron	(107) Madison	(108) Oregon
(109) Reynolds	(110) Ripley	(111) St.Francois	(112) Shannon
(113) Washington	(114) Wayne		

Southwest Ozarks Unit

(201) Barry	(202) Christian	(203) Douglas	(204) Howell
(205) McDonald	(206) Newton	(207) Ozark	(208) Stone
(209) Taney	(210) Texas	(211) Webster	(212) Wright

Northwest Ozarks Unit

(301) Benton	(302) Camden	(303) Cedar	(304) Dallas
(305) Hickory	(306) Laclede	(307) Maries	(308) Miller
(309) Morgan	(310) Phelps	(311) Polk	(312) Pulaski
(313) St.Clair			

Data base number and name (XIII) MORBNW

Prairie Unit

(401) Adair	(402) Andrew	(403) Atchison	(404) Audrain
(405) Barton	(406) Bates	(407) Buchanan	(408) Caldwell
(409) Carroll	(410) Cass	(411) Chariton	(412) Clark
(413) Clay	(414) Clinton	(415) Cooper	(416) Dade
(417) Daviess	(418) De Kalb	(419) Gentry	(420) Greene
(421) Grundy	(422) Harrison	(423) Henry	(424) Holt
(425) Jackson	(426) Jasper	(427) Johnson	(428) Knox
(429) Lafayette	(430) Lawrence	(431) Lewis	(432) Lincoln
(433) Linn	(434) Livingston	(435) Macon	(436) Marion
(437) Mercer	(438) Monroe	(439) Nodaway	(440) Pettis
(441) Pike	(442) Platte	(443) Putnam	(444) Rallis
(445) Randolph	(446) Ray	(447) Saline	(448) Schuyler
(449) Scotland	(450) Shelby	(451) Sullivan	(452) Vernon
(453) Worth			

Riverborder Unit

(501) Boone	(502) Callaway	(503) Cape Girardeau	(504) Cole
(505) Dunkin	(506) Franklin	(507) Gasconade	(508) Howard
(509) Jefferson	(510) Mississippi	(511) Moniteau	(512) Montgomery
(513) New Madrid	(514) Osage	(515) Pemiscot	(516) Perry
(517) Saint Charles	(518) Saint Louis	(519) Sainte Genevie	
(520) Scott	(521) Stoddard	(522) Warren	
(523) City of Saint Louis			

Southern Unit

(101) Alexander	(102) Franklin	(103) Gallatin	(104) Hamilton
(105) Hardin	(106) Jackson	(107) Johnson	(108) Massac
(109) Perry	(110) Pope	(111) Pulaski	(112) Randolph
(113) Saline	(114) Union	(115) White	(116) Williamson

Claypan Unit

(201) Bond	(202) Calhoun	(203) Clark	(204) Clay
(205) Clinton	(206) Crawford	(207) Cumberland	(208) Edwards
(209) Effingham	(210) Fayette	(211) Greene	(212) Jasper
(213) Jefferson	(214) Jersey	(215) Lawrence	(216) Macoupin
(217) Madison	(218) Marion	(219) Monroe	(220) Montgomery
(221) Richland	(222) St. Clair	(223) Shelby	(224) Wabash
(225) Washington	(226) Wayne		

Code	County name	Code	County name	Code	County name	Code	County name
Prairie Unit							
(301)	Adams	(302)	Boone	(303)	Brown	(304)	Bureau
(305)	Carroll	(306)	Cass	(307)	Champaign	(308)	Christian
(309)	Coles	(310)	Cook	(311)	De Kalb	(312)	Dewitt
(313)	Douglas	(314)	Dupage	(315)	Edgar	(316)	Ford
(317)	Fulton	(318)	Grundy	(319)	Hancock	(320)	Henderson
(321)	Henry	(322)	Iroquois	(323)	Jo Daviess	(324)	Kane
(325)	Kankakee	(326)	Kendall	(327)	Knox	(328)	Lake
(329)	La Salle	(330)	Lee	(331)	Livingston	(332)	Logan
(333)	Macon	(334)	Marshall	(335)	Mason	(336)	McDonough
(337)	McHenry	(338)	McLean	(339)	Menard	(340)	Mercer
(341)	Morgan	(342)	Moultrie	(343)	Ogle	(344)	Peoria
(345)	Piatt	(346)	Pike	(347)	Putnam	(348)	Rock Island
(349)	Sangamon	(350)	Schuyler	(351)	Scott	(352)	Stark
(353)	Stephenson	(354)	Tazewell	(355)	Vermillion	(356)	Warren
(357)	Whiteside	(358)	Will	(359)	Winnebago	(360)	Woodford

State = Indiana   State code = 18
Data base number and name   (XV) INDIANA

Lower Wabash Unit							
(101)	Clay	(102)	Daviess	(103)	Gibson	(104)	Greene
(105)	Knox	(106)	Martin	(107)	Parke	(108)	Pike
(109)	Posey	(110)	Putnam	(111)	Sullivan	(112)	Vanderburg
(113)	Vermillion	(114)	Vigo				
Knobs Unit							
(201)	Brown	(202)	Clark	(203)	Crawford	(204)	Dubois
(205)	Floyd	(206)	Harrison	(207)	Jackson	(208)	Lawrence
(209)	Monroe	(210)	Morgan	(211)	Orange	(212)	Owen
(213)	Perry	(214)	Scott	(215)	Spencer	(216)	Warrick
(217)	Washington						
Upland Flats Unit							
(301)	Dearborn	(302)	Fayette	(303)	Franklin	(304)	Jennings
(305)	Jefferson	(306)	Ohio	(307)	Ripley	(308)	Switzerland
(309)	Union						
Northern Unit							
(401)	Adams	(402)	Allen	(403)	Bartholomew	(404)	Benton
(405)	Blackford	(406)	Boone	(407)	Carroll	(408)	Cass
(409)	Clinton	(410)	Decatur	(411)	De Kalb	(412)	Delaware
(413)	Elkhart	(414)	Fountain	(415)	Fulton	(416)	Grant
(417)	Hamilton	(418)	Hancock	(419)	Hendricks	(420)	Henry
(421)	Howard	(422)	Huntington	(423)	Jasper	(424)	Jay
(425)	Johnson	(426)	Kosciusko	(427)	La Grange	(428)	Lake
(429)	La Porte	(430)	Madison	(431)	Marion	(432)	Marshall
(433)	Miami	(434)	Montgomery	(435)	Newton	(436)	Noble
(437)	Porter	(438)	Pulaski	(439)	Randolph	(440)	Rush
(441)	St. Joseph	(442)	Shelby	(443)	Starke	(444)	Steuben
(445)	Tippecanoe	(446)	Tipton	(447)	Wabash	(448)	Warren
(449)	Wayne	(450)	Wells	(451)	White	(452)	Whitley

Codes for variables R4 PICODE, R5 PISTRAT

The use of these variables was described in section I sampling and estimation procedures. The actual codes vary from State to State. PICODE generally indicates a broad land use category such as (10 or 20) forest, (50 or 60) nonforest, (30) questionable, and (80 or 90) water. PISTRAT indicates a broad forest type and stand-size density class using codes similar to but not identical to variables C4 FORTCUR and R21 SZDNCUR.

Codes for variable R9 UTREND

The first two digits describe the land class change that took place between surveys or the change since the date of photography. Codes to be used for the first two digits are divided into the following two categories:

When land class is not commercial forest on both occasions:

First two digits--The first digit is the code for the present land class. The second digit is the code of the land class at the time of the last survey or the date of photography.

Code	Land Use Class
1	Commercial forest
2	Productive reserved forest
3	Unproductive forest
4	Cropland
5	Pasture, rangeland
6	Idle farmland
7	Wooded pasture
8	Urban, recreation, wooded strips, rights of way, other
9	Water and marsh

For commercial forest land on both occasions:

First two digits--The codes are used to indicate any major changes in the stand since the last survey or the date of photography.

If there has been a disturbance in the sampling area since the date of photography but the forest type or stand-size class has not changed, it will be recorded as no change. This disturbance could be recorded under stand history.

Code	Stand changes
10	No change
01	Forest type change
02	Stand-size change
03	Forest type and size change

The third digit indicates the process that caused the change and uses one of the following codes:

Code	Cause of Land Use Change
0	No change
1	Definition
2	Legislation
3	Natural
4	Herbicide
5	Clearing (land cleared by mechanical or hand means but timber not utilized)
6	Clearcut (includes land clearing where timber is utilized)

7 Partial cut
8 Planting
9 Other man (includes fencing to exclude livestock)

mples: 1. Commercial forest land (Red Pine Plantation) now, on the photo was idle farmland, use trend code 168.

2. Marsh without trees now, on photo was marsh with trees, use trend code 990.

3. Cleared powerline right of way now, on photo was commercial forest land. Timber utilized, use trend code 816.

es for variables R10 STDHIST, R11 PRJSTDH

Stand history reflects the kind of disturbance on five or more of the sample nts within the last 20 years.

Explain the kind and extent of any disturbance in the "Notes" on the back the plot sheet. Use the following 2-digit code to record stand history:

st digit (what happened)		Second digit (how long ago)	
1	No disturbance	0	No disturbance
2	Timber stand improvement	1	1-4 years
3	Clearcut	2	5-10 years
4	Partial harvest cut	3	11-15 years
5	Natural--fire, insects, disease	4	15-20 years
6	Man caused--drainage, spraying		
7	Planting of forest land		
8	Planting of nonforest land		
9	Natural regeneration of non-forest land		

es for variable R35 AREACOND

) Areas fully stocked with desirable trees but not overstocked.

) Areas fully stocked with desirable trees but overstocked with all live trees.

) Areas medium to fully stocked with desirable trees and with less than 30 percent of the area controlled by other trees and/or inhibiting vegetation or surface conditions that will prevent occupancy by desirable trees.

) Areas medium to fully stocked with desirable trees and with 30 percent or more of the area controlled by other trees and/or conditions that ordinarily prevent occupancy by desirable trees.

) Areas poorly stocked with desirable trees but fully stocked with growing-stock trees.

(60) Areas poorly stocked with desirable trees but with medium to full stocking of growing-stock trees.

(70) Areas poorly stocked with desirable trees and poorly stocked with growing-stock trees.

Codes for variable R10 CAVIT

At each sample point, each live tree 5.0 inches DBH and larger is examined for cavities used fo nesting, resting or storage by birds or mammals. For the largest cavity a 2-digit code is recorded indicate the size of the cavity entrance hole and location of the cavity in the tree. The first di indicates the cavity hole size, the second digit indicates the location of the cavity.

To qualify as a cavity, the entrance hole must be 1.0 inch or larger in the main stem, fork, or lar limb. (A large limb must be greater than 8.0 inch in diameter o.b.). If no cavity is present, thi item is zero or missing.

missing.

First digit		Second digit	
Code	Size of opening (inches)	Code	Location of cavity (feet)
1	1	1	0-1
2	2	2	2-5
3	3	3	6-9
4	4	4	10-19
5	5	5	20-29
6	6	6	30-39
7	7	7	40-49
8	8	8	50-59
9	9+	9	60+

Codes for variables C4 FORTCUR, R20 FORTPRJ, R23 FORTORG

(For detailed definitions of these forest types see page 14)

States = Michigan, Wisconsin, Minnesota
Data base numbers and names
(I)MICHUP, (II)MICHLP, (III)WISNOR, (IV)WISSOU, (V)MINNOR, (VI)MINSOU

Code Forest type	Code Forest type
(1) Jack pine	(2) Red pine
(3) White pine	(6) Exotic
(12) Black spruce	(13) Balsam fir
(14) Northern white-cedar	(15) Tamarack
(16) White spruce	(50) Oak-hickory
(70) Elm-ash-soft maple	(80) Maple-birch
(91) Aspen	(92) Paper birch

States = North Dakota, South Dakota, Nebraska, Kansas
Data base numbers and names
(VII)NDAKOTA, (VIII)SDAKOTA, (IX)NEBRASK, (X)KANSAS

(42) Cedar-hardwood	(50) Oak-hickory
(51) Post-blackjack oak	(59) Upland plains hwds.
(70) Elm-ash-cottonwood	(74) Willow
(73) Cottonwood	(87) Upland elm-ash-loc.
(77) Lowland plains hwds.	

State = Iowa
Data base number and name (XI)IOWA

(42) E.redcedar-hardwood	(50) Oak-hickory
(54) White oak	(59) Bur oak
(70) Elm-ash-cottonwood	(73) Cottonwood
(80) Maple-basswood	(91) Aspen

State = Missouri
Data base numbers and names (XII)MOZARK, (XIII)MORBNW

Code Forest type	Code Forest t
(32) Shortleaf pine	(35) Eastern
(42) Redcedar-hardwood	(44) Shortlea pine-oak
(51) Post-blackjack oak	
(53) Black-scarlet oak	(54) White oa
(60) Oak-gum-cypress	(70) Elm-ash- cottonwo
(73) Cottonwood	
(80) Maple-beech	

States = Illinois,Indiana
Data base numbers and names (XIV)ILLINI, (XV)INDIANA

(30) Loblolly-shortleaf pine	(40) Oak-pine
(50) Oak-hickory	(60) Oak-gum-
(70) Elm-ash-cottonwood	
(80) Maple-beech-birch	
(90) Aspen-birch	

s for species variables R16 CUNSPP, R28 SISPP, R4 SPECIES, R3 SPPSI

Commercial species

e	Common name	Scientific name
2	Balsam fir	Abies balsamea var.
8	Eastern redcedar	Juniperus virginiana
0	European larch	Larix decidua
1	Tamarack	Larix laricina
1	Norway spruce	Picea abies
3	Engelmann spruce	Picea engelmannii
4	White spruce	Picea glauca
5	Black spruce	Picea mariana
6	Col. blue spruce	Picea pungens
5	Jack pine	Pinus banksiana
3	Limber pine	Pinus flexilis
2	Ponderosa pine	Pinus ponderosa
5	Red pine	Pinus resinosa
9	White pine	Pinus strobus
0	Scotch pine	Pinus sylvestris
3	Austrian pine	Pinus nigra
2	Douglas fir	Pseudotsuga menziesii
1	N. white-cedar	Thuja occidentalis
1	Hemlock	Tsuga canadensis
0	Acacia	Acacia spp.
3	Boxelder	Acer negundo
4	Black maple	Acer nigrum
6	Red maple	Acer rubrum
7	Silver maple	Acer saccharinum
8	Sugar maple	Acer saccharum
1	Ohio buckeye	Aesculus glabra
1	Yellow birch	Betula alleghaniensis
2	Sweet birch	Betula lenta
3	River birch	Betula nigra
4	Water birch	Betula occidentalis
5	Paper birch	Betula papyrifera
[illegible]	Bitternut hickory	Carya cordiformis
[illegible]	Pignut hickory	Carya glabra
[illegible]	Pecan	Catya illinoensis
[illegible]	Shellbark hickory	Carya laciniosa
[illegible]	Shagbark hickory	Carya ovata
[illegible]	Black hickory	Carya texana
[illegible]	Mockernut hickory	Carya tomentosa
[illegible]	American chestnut	Castanea dentata
[illegible]	Northern catalpa	Catalpa speciosa
6	Sugarberry	Celtis laevigata
6	Hackberry	Celtis occidentalis
9	Flowering dogwood	Cornus florida
2	Persimmon	Diospyros virginiana
3	Beech	Fagus grandifolia
4	White ash	Fraxinus americana
4	Black ash	Fraxinus nigra
4	Green ash	Fraxinus pennsylvanica
4	Blue ash	Fraxinus quadrangulata
5	Honeylocust	Gleditsia triacanthus
7	Ky. coffee tree	Gymnocladus dioicus
0	Butternut	Juglans cinerea
0	Black walnut	Juglans nigra
2	Yellow poplar	Liriodendron tulipifera
6	Apple	Malus spp.
8	White mulberry	Morus alba
8	Red mulberry	Morus rubra
9	Black tupelo	Nyssa sylvatica
3	Sycamore	Platanus occidentalis
4	Balsam poplar	Populus balsamifera
4	East. cottonwood	Populus deltoides
4	Bigtooth aspen	Populus grandidentata
4	Plains cottonwood	Populus sargentii
4	Quaking aspen	Populus tremuloides
5	Silver poplar	Populus alba

Code	Common name	Scientific name
753	Narrowleaf ctnwd.	Populus angustifolia
762	Black cherry	Prunus serotina
802	White oak	Quercus alba
804	Swamp white oak	Quercus bicolor
806	Scarlet oak	Quercus coccinea
809	Northern pin oak	Quercus ellipsoidalis
817	Shingle oak	Quercus imbricaria
823	Bur oak	Quercus macrocarpa
824	Blackjack oak	Quercus marilandica
826	Chinkapin oak	Quercus muehlenbergii
830	Pin oak	Quercus palustris
832	Chestnut oak	Quercus prinus
833	Northern red oak	Quercus rubra
834	Shumard oak	Quercus shumardii
835	Post oak	Quercus stellata
837	Black oak	Quercus velutina
901	Black locust	Robinia pseudoacacia
922	Black willow	Salix nigra
931	Sassafras	Sassafras albidum
951	American basswood	Tilia americana
972	American elm	Ulmus americana
974	Siberian elm	Ulmus pumila
975	Slippery elm	Ulmus rubra
977	Rock elm	Ulmus thomasii

Noncommercial species

Code	Common name	Scientific name
066	Rocky mt. juniper	Juniperus scorplorum
315	Striped maple	Acer pensylvanicum
319	Mountain maple	Acer spicatum
321	Rocky mt. maple	Acer glabrum
333	Western buckeye	Aesculus glabra
341	Ailanthus	Ailanthus altissima
391	Am. hornbeam	Carpinus caroliniana
471	Eastern redbud	Cercis canadensis
500	Hawthorn	Crataegus species
641	Osage orange	Maclura pomifera
701	Ironwood	Ostrya virginiana
761	Pincherry	Prunus pensylvanica
763	Chokecherry	Prunus virginiana
765	Canada plum	Prunus nigra
766	Wild plum	Prunus americana
851	Mountain ash	Sorbus
921	Peachleaf willow	Salix amygdaloides
923	Diamond willow	Salix eriocephala

Codes for record type 4 variable R2 SHRUBSP tall woody shrubs

Code	Common name	Scientific name
351	Red alder	Alnus rubra
352	Green alder	Alnus crispa
353	Speckled alder	Alnus rugosa
380	Swamp birch	Betula pumila
381	Dwarf birch	Betula glandulosa
463	Dwarf hackberry	Celtis tenuiflolia
490	Dogwood	Cornaceae
592	Black alder	Ilex verticillata
593	Mountain holly	Nemopanthus mucronata
594	Deciduous holly	Ilex decidua
603	Spice bush	Lindera benzoin
764	Sandcherry	Prunus pumila
767	Pawpaw	Asimina triloba
768	Devils wlk. stick	Asimina triloba
769	Chickasaw plum	Prunus angustifolia
850	Sweet gale	Myrica gale
852	Common barberry	Berberis vulgaris

853 Witch hazel	Hamamelis virginiana
854 Common ninebark	Physocarpus opulifolius
855 Juneberry	Amelanchier
856 Beaked hazenut	Corylus cornuta
857 Prickly ash	Zanthoxylum americanum
859 Buckthorn	Rhamnus
860 Mountain laurel	Ceanothus sanguineus
861 Leatherwood	Dirca palustris
862 Vibernum	Viburnum
863 Elderberry	Sambucus
864 Sumac	Rhus
869 Shrubby trefoil	Ptelea trifoliata
880 Buffaloberry	Shepherdia canadensus
903 Poison sumac	Rhus vernix
907 New Jersey tea	Ceanothus americanus
912 Buttonbush	Cephalanthus occidentalis
913 Russian olive	Elaeagnus
915 Wild crabapple	Pyrus ioensis
916 Lead plant	Amorpha
917 Wahoo	Euonymus atropurpurea
919 Soapberry	Sapindus drummondii
920 Willow	Salicaceae
925 Tamarisk	Amarix gallica
926 Buckthorn	Umelia lanuginosa
927 Rabbitbush	Chrysothamnus pulchell
997 Other species	(tall, perennials)

odes for record type 5 variable R2 SHUSPL low herbaceous shrubs.

059 Creeping juniper	Juniperus horizontalis
069 Common juniper	Juniperus communis
230 Yew	Taxus canadensis
590 Holly	Ilex
712 Virginia creeper	Parthenocissus
748 Spirea	Spiraea
749 Labrador tea	Ledum groenlandicum
750 Leatherleaf	Chamaedaphne calyculat
751 Bog laurel	Kalmia polifolia
849 Sweetfern	Comptonia peregrina
865 Gooseberry	Ribes
866 Chokeberry	Aronia
867 Rasp.-blackberry	Rubus
868 Rose	Rosa
870 Am. bladdernut	Staphylea trifolia
871 Willow herb	Decodon verticillatus
872 Privet andromeda	Lyonia liqustrina
873 Black huckleberry	Gaylussacia baccata
74 Bil.-blueberry	Vaccinium
75 Bush honeysuckle	Diervilla lonicera
76 Honeysuckle	Lonicera
77 Buckbrush	Symphoricarpus
78 Shrb. cinquefoil	Potentilla fruticosa
02 Poison ivy	Rhus radicans
08 St.johns wort	Hypericum
09 Bearberry	Arctosttaphylos uva-ur
18 Bittersweet	Celastrus scandens
24 Raccoon grape	Ampelopsis cordata
29 Sandhill sage	Artemisia filifolia
32 Greenbriar	Smilax
78 Bog rosemary	Andromeda glaucophylla
82 Grape	Vitis
83 Clematis	Vitis
84 Strawberry	Fragaria spp.
98 Other species	(other perennials)

APPENDIX B.--GLOSSARY OF TERMS

Acceptable trees.--Growing-stock trees of commercial species that meet specified standards of size and quality but do not qualify as desirable trees.

Basal area.--The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Biomass.--The above-ground volume of all live trees (including bark and foliage) reported in green tons. Biomass is made up of five components:

Growing-stock bole.--Biomass of a growing-stock tree from a 1-foot stump to a variable 4-inch top.

Growing-stock tops and limbs.--Biomass of a growing-stock tree from a 1-foot stump minus the growing-stock bole.

Cull bole.--Biomass of a cull tree from a 1-foot stump to a variable 4-inch top.

Cull tops and limbs.--Biomass of a cull tree from a 1-inch stump minus the cull bole.

1- to 5-inch trees.--Biomass of all live trees 1 to 5 inches in diameter at breast height.

Commercial forest land.--Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as commerial forest land are capable of producing more than 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for producing industrial wood in the foreseeable future.) Also see definition of pastured commercial forest land.

Commercial species.--Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

County and municipal land.--Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

Cull.--Portions of a tree that are unusable for industrial wood products, because of rot, form, or other defect.

Desirable tree.--Growing-stock tree that has no serious defects in quality limiting present or prospective use, having relatively high vigor, and containing no pathogens that may kill or seriously deteriorate it before rotation age. These trees would be favored by forest managers in silvicultural operations.

Diameter classes.--A classification of trees based on diameter outside bark, measured at breast height (4.5 feet above the ground). (Note: d.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Survey, with the even inch the approximate midpoint for a class. For example, the 6-inch class includes trees 5.0 through 6.9 inches d.b.h.)

Farm.--Either a place operated as a unit or 10 or more acres from which the sale of agricultural products totals $50 or more annually, or a place operated as a unit of le than 10 acres from which the sale of agricultural products for a year amounts to at least $250. Places having less than the $5 or $250 minimum estimated sales in a given year are also counted as farms if they can normally be expected to produce goods in sufficient quantity to meet the requiremen of the definition.

Farmer-owned land.--Land owned by farm operato (Note: Excludes land leased by farm operators from nonfarm owners, such as railroad companies and States.)

Forest land.--Land at least 16.7 percent stock by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note Stocking is measured by comparison of basa area and/or number of trees, by age or siz and spacing with specified standards.) Th minimum area for classification of forest land is one acre. Roadside, streamside, a shelterbelt strips of timber must have a a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water clearings in forest areas shall be classed as forest if less than 120 feet wide. Als see definitions for land area, commercial forest land, noncommercial forest land, productive-reserved forest land, stocking, unproductive forest land, and water.

Forest industry land.--Land owned by companies or individuals operating primary wood-usin plants.

Forest trees.--Woody plants having a well-developed stem and usually more than 12 feet ta at maturity.

Forest type.--A classification of forest land based on the species forming a plurality o live tree stocking. Major forest types are:

Jack pine.--Forests in which jack pin comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.--Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.--Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.--Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.--Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include balsam fir, aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.--Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.--Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.--Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Shortleaf pine.--Forests in which shortleaf pine comprises a plurality of the stocking. (Common associates include oak, hickory, and gum.)

Loblolly-shortleaf pine.--Forests in which loblolly, shortleaf, and Virginia pines, singly or in combination, comprise a plurality of the stocking. (Common associates include gum, hickory, sassafras, and yellow-poplar.)

Eastern redcedar.--Forests in which eastern redcedar comprises a plurality of the stocking. (Common associates are oak and hickory.)

Eastern redcedar-hardwood.--Forests in which hardwoods comprise a plurality of the stocking but in which eastern redcedar comprises 25 percent or more of the stocking. Found on dry uplands, usually abandoned pastures or fields.

Shortleaf pine-oak.--Forests in which upland oaks comprise a plurality of the stocking, but in which shortleaf pine comprises 25 to 50 percent of the stocking.

Oak-hickory.--Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, beech, yellow-poplar, elm, and maple.)

Post-blackjack oak.--Forests in which post oak or blackjack oak, singly or in combination, comprise a majority of the stocking. Occurs on dry uplands and ridges.

Black-scarlet oak.--Forests in which upland oaks or hickory, singly or in combination, comprises a plurality of the stocking except where shortleaf pine or redcedar comprises 25 to 50 percent, or where white oak or post and blackjack oak comprise a plurality. (Common associates include yellow-poplar, elm, maple, and black walnut.)

White oak.--Forests in which white oak comprises more than 50 percent of the primary typing species for the oak-hickory type. (Common associates are black oak, northern red oak, bur oak, shagbark and bitternut hickories, white ash, and bigtooth aspen.)

Bur oak.--Forests in which bur oak comprises more than 50 percent of the stocking of the primary typing species for the oak-hickory type. (Common associates are northern pin oak, northern red oak, white oak, black oak, basswood, American elm, green ash, boxelder, hackberry, cottonwood, and hophornbeam.)

Upland plains hardwoods.--Forests in which black walnut, hackberry, and bur oak, singly or in combination, comprise a plurality of the stocking. Commonly found on slopes and uplands.

Oak-gum-cypress.--Bottomland forests in which bottomland oaks such as pin, swamp white, and shingle oaks, along with tupelo, blackgum, sweetgum, and cypress, singly or in combination, comprise a plurality of the stocking. (Common associates include cottonwood, willow, ash, elm, hackberry, and maple.)

Elm-ash-soft maple.--Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Elm-ash-cottonwood.--Lowland forests in which elm, ash, cottonwood, and willow, singly or in combination, comprise a plurality of the stocking, except for those in which cottonwood or willow comprise a majority of the stocking. Found on first or second bottoms of major streams.

Cottonwood.--Forests in which cottonwood comprises a majority of the stocking.

Willow.--Forests in which willow comprises a majority of the stocking.

Lowland plains hardwoods.--Forests in which black walnut, hackberry, bur oak, soft maple, and boxelder, singly or in combination comprise a plurality of the stocking. Commonly found in coves and bottomlands.

Maple-birch.--Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

Maple-beech.--Forests in which hard maple or beech, singly or in combination, comprises a plurality of the stocking. (Common associates include elm and basswood.)

Hard maple-basswood.--Forests in which sugar maple or basswood, singly or in combination, comprise a plurality of the stocking. (Common associates are American elm, green ash, yellow birch, white pine, and northern red oak.)

Upland elm-ash-locust.--Upland forests in which elm, ash, and honeylocust, singly or in combination, comprise a plurality of the stocking. Includes shelterbelts and windbreaks on sites drier than those commonly associated with lowland species.

Aspen.--Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.) and red maple, singly

or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Paper birch.--Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Exotic.--Forests in which species not native to the State comprise a plurality of the stocking. (Mostly Scotch pine plantations.)

Gross area.--The entire area of land and water as determined by the Bureau of the Census, 1970.

Growing-stock trees.--Live trees of commercial species qualifying as desirable and acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.--Net volume in cubic feet of growing-stock trees 5.0 inches d.b.h. and over, from a 1-foot stump to a minimum 4.0 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to cords by dividing by 79 cubic feet per solid wood cord.

Hardwoods.--Dicotyledonous trees, usually broad-leaved and deciduous.

Idle farmland.--Includes former cropland, orchards, improved pastures, and farm sites not tended within the past 2 years and presently less than 16.7 percent stocked with trees.

Improved pasture.--Land currently improved for grazing by cultivating, seeding, irrigating or clearing of trees or brush and less than 16.7 percent stocked with live trees.

Indian land.--All lands held in trust by the United States for individual Indians or tribes, or all lands, titles to which are held by individual Indians or tribes, subject to Federal restrictions against alienation.

Land area.--A. Bureau of the Census. The area area of dry land and land temporarily or partly covered by water such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs, estuaries, and canals less than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

B. Forest Inventory and Analysis.--The same as the Bureau of the Census, except minimum width of streams, etc., is 120 feet and minimum size of lakes, etc., is 1 acre.

Live trees.--Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

Log grades.--A classification of logs based on external characteristics as indicators of quality or value. (See Appendix for specific grading factors used.)

Logging residues.--The unused growing stock portions of trees cut or killed by logging.

Maintained road.--Any road, hard-topped or other surfaces, that is plowed or graded at least once a year. Includes rights-of-way that are cut or treated to limit herbaceous growth.

Marsh.--Nonforest land that characteristically supports low, generally herbaceous or shrubby vegetation and that is intermittently covered with water.

Merchantable.--Refers to a pulpwood or saw log section that meets pulpwood or saw log specifications, respectively.

Miscellaneous federal land.--Federal land other than National Forest, land administered by the Bureau of Land Management, and Indian land.

Miscellaneous private land.--Privately owned land other than forest-industry and farmer-owned land.

Mortality.--The volume of sound wood in growing-stock and sawtimber trees that die annually.

National Forest land.--Federal land that has been legally designated as National Forest or purchase units, and other land administered by the USDA Forest Service.

Net annual growth of growing-stock.--The annual change in volume of sound wood in live sawtimber and poletimber trees and the total volume of trees entering these classes through ingrowth, less volume losses resulting from natural causes.

Net annual growth of sawtimber.--The annual change in the volume of live sawtimber trees and the total volume of trees reaching sawtimber size, less volume losses resulting from natural causes.

Net volume.--Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Noncommercial forest land.--(a) Unproductive forest land and (b) productive-reserved forest land.

Noncommercial species.--Tree species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial wood products.

Nonforest land.--Land that has never supported forests, and land formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide and more than 1 acre in area to qualify as nonforest land.)

a. Nonforest land without trees.--Nonforest land with no live trees present.

b. Nonforest land with trees.--Nonforest land with one or more trees per acre at least 5 inches d.b.h.

Nonstocked land.--Commercial forest land less than 16.7 percent stocked with growing-stock trees.

Other removals.--Growing-stock trees removed but not utilized for products, or trees left standing but "removed" from the commercial forest land classification by land use change. Examples are removals from cultura operations such as timber stand improvement work, land clearing, and changes in land use.

Ownership.--Property owned by one owner, regardless of the number of parcels in a specified area.

Ownership size class.--The amount of commmercial forest land owned by one owner, regardless of the number of parcels.

Owner tenure.--The length of time a property has been held by the owner.

Physiographic class.--A measure of soil and water conditions that affect tree growth on a site. The physiographic classes are:

Xeric sites.--Very dry soils where excessive drainage seriously limits both growth and species occurrence. Example: sandy jack pine plains.

Xeromesic sites.--Moderately dry soils where excessive drainage limits growth and species occurrence to some extent. Example: dry oak ridge.

Mesic sites.--Deep, well-drained soils. Growth and species occurrence are limited only by climate.

Hydromesic sites.--Moderately wet soils where insufficient drainage or infrequent flooding limits growth and species occurrence to some extent. Example: better drained bottomland hardwood sites.

Hydric sites.--Very wet sites where excess water seriously limits both growth and species occurrence. Example: extra spruce wet, frequently flooded river bottoms and spruce bogs.

Plant byproducts.--Plant residues used for products such as mulch, pulp chips, and fuelwood.

Plant residues.--Wood and bark materials generated at manufacturing plants during production of other products.

Poletimber stands.--(See stand-size class.)

Poletimber trees.--Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber

Productive-reserved forest land.--Forest land sufficiently productive to qualify as commercial forest land but withdrawn from timber utilization through statute, administration regulation, designation, or exclusive use for Christmas tree production, as indicated by annual shearing.

Productive-deferred.--Forest land sufficiently productive to qualify as commercial forest land but presently withdrawn from timber utilization because it is being considered for possible inclusion into the Wilderness system.

Rotten trees.--Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications cations for freedom from defect primarily because of rot; that is, when more than 50 percent of extra cull volume in a tree is rotten.

Rough trees.--(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Roundwood products.--Logs, bolts, or other round sections (including chips from roundwood) cut from trees for industrial or consumer uses. (Note: Includes saw logs, veneer logs and bolts; cooperage logs and bolts; pulpwood; fuelwood; piling; poles; posts; hewn ties; mine timbers; and various other round, split, or hewn products.)

Salvable dead trees.--Standing or down dead trees that are considered merchantable by regional standards.

Saplings.--Live trees 1- to 5 inches d.b.h.

Sapling-seedling stands.--(See stand-size class.)

Saw log.--A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by regional standards.

Saw log portion.--That part of the bole of sawtimber trees between the stump and the saw log top.

Saw log top.--The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for softwoods and 9 inches d.o.b. for hardwoods.

Sawtimber stands.--(See stand-size class.)

Sawtimber trees.--Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting regional specifications for freedom from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

Sawtimber volume.--Net volume of the saw log portion of live sawtimber in board feet, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Seedlings.--Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

Short-log (rough tree).--Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Shrub biomass.--The total aboveground weight (including the bark) of selected shrubs and trees less than 1 inch d.b.h.

Site class.--A classification of forest land in terms of inherent capacity to grow crops of industrial wood based on fully stocked natural stands.

Site index.--An expression of forest site quality based on the total height of free-growing dominant or codominant trees of a representative species in the forest type at age 50.

Softwoods.--Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.--A growth of trees on a minimum of 1 acre

of forest land that is stocked by forest trees of any size.

Stand-age class.--Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.--The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

Stand-size class.--A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber, or seedlings and saplings.

a. Sawtimber stands.--Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

b. Poletimber stands.--Stands at least 16.7 percent stocked with growing-stock trees of which half or more of this stocking is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

c. Sapling-seedling stands.--Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the stocking is saplings and/or seedlings.

d. Nonstocked stands.--Stands in which stocking of growing-stock trees is less than 16.7 percent.

State land.--Land owned by States, or land leased to these governmental units for 50 years or more.

Stocking.--The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard. A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h. Stands are grouped into the following stocking classes:

Overstocked stands.--Stands in which stocking of trees is 134.0 percent or more.

Fully stocked stands.--Stands in which stocking of trees is from 101.0 to 133.9 percent.

Medium stocked stands.--Stands in which stocking of trees is from 61.0 to 100.9 percent.

Poorly stocked stands.--Stands in which stocking of trees is from 16.7 to 60.9 percent.

Nonstocked areas.--Commercial forest land on which stocking of trees is less than 16.7 percent.

Timber removals from growing stock.--The volume of sound wood in growing-stock trees removed annually for forest products (including roundwood products and logging residues) and for other removals.

Timber removals from sawtimber.--The net board-foot volume of live sawtimber trees removed for forest products annually (including roundwood products and logging residues) and for other removals.

Timber products output.--All timber products cut from roundwood and byproducts of wood manufacturing plants. Roundwood products include logs, bolts, or other round sections cut from growing-stock trees, cull trees, salvable dead trees, trees on nonforest land, noncommercial species, sapling-size trees, and limbwood. Byproducts from primary manufacturing plants include slabs, edging, trimmings, miscuts, sawdust, shavings, veneer cores and clippings, and screenings of pulpmills that are used as pulpwood chips or other products.

Tree biomass.--The total aboveground weight (including the bark) of all trees from 1 to 5 inches in d.b.h., and the total aboveground weight (including the bark) from a 1-foot stump for trees more than 5 inches in diameter.

Tree size class.--A classification of trees based on diameter at breast height, including sawtimber trees, poletimber trees, saplings, and seedlings.

Unproductive forest land.--Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soils, dry climate, poor drainage, high elevation, steepness, and rockiness).

Upper stem portion.--That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Urban and other areas.--Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards, cemeteries, roads; railroads; airports; beaches; powerlines; and other rights-of-way; or other nonforest land not included in any other specified land use class.

Water.--(a) Bureau of the Census.--Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 40 acres or more of area; streams, sloughs, estuaries, and canals one-eighth of a statute mile or more in width.

(b) Noncensus.--Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 1 to 39.9 acres of area; streams, sloughs estuaries, and canals 120 feet to one-eighth of a statute mile wide.

Wooded pasture.--Improved pasture with more than 16.7 percent stocking in live trees but less than 25 percent stocking in growing-stock trees. Area is currently improved for grazing or there is other evidence of grazing.

Wooded strip.--An acre or more of natural continuous forest land that would otherwise meet survey standards for commercial forest land except that it is less than 120 feet wide

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Data bases for forest inventory in the North-Central Region. Gen. Tech. Rep. NC-101. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 57 p.

Describes the data collected by the Forest Inventory and Analysis (FIA) Research Work Unit at the North Central Forest Experiment Station. Explains how interested parties may obtain information from the data bases either through direct access or by special requests to the FIA data base manager.

KEY WORDS: Forest survey, data retrieval, sampling procedures, data base management system.

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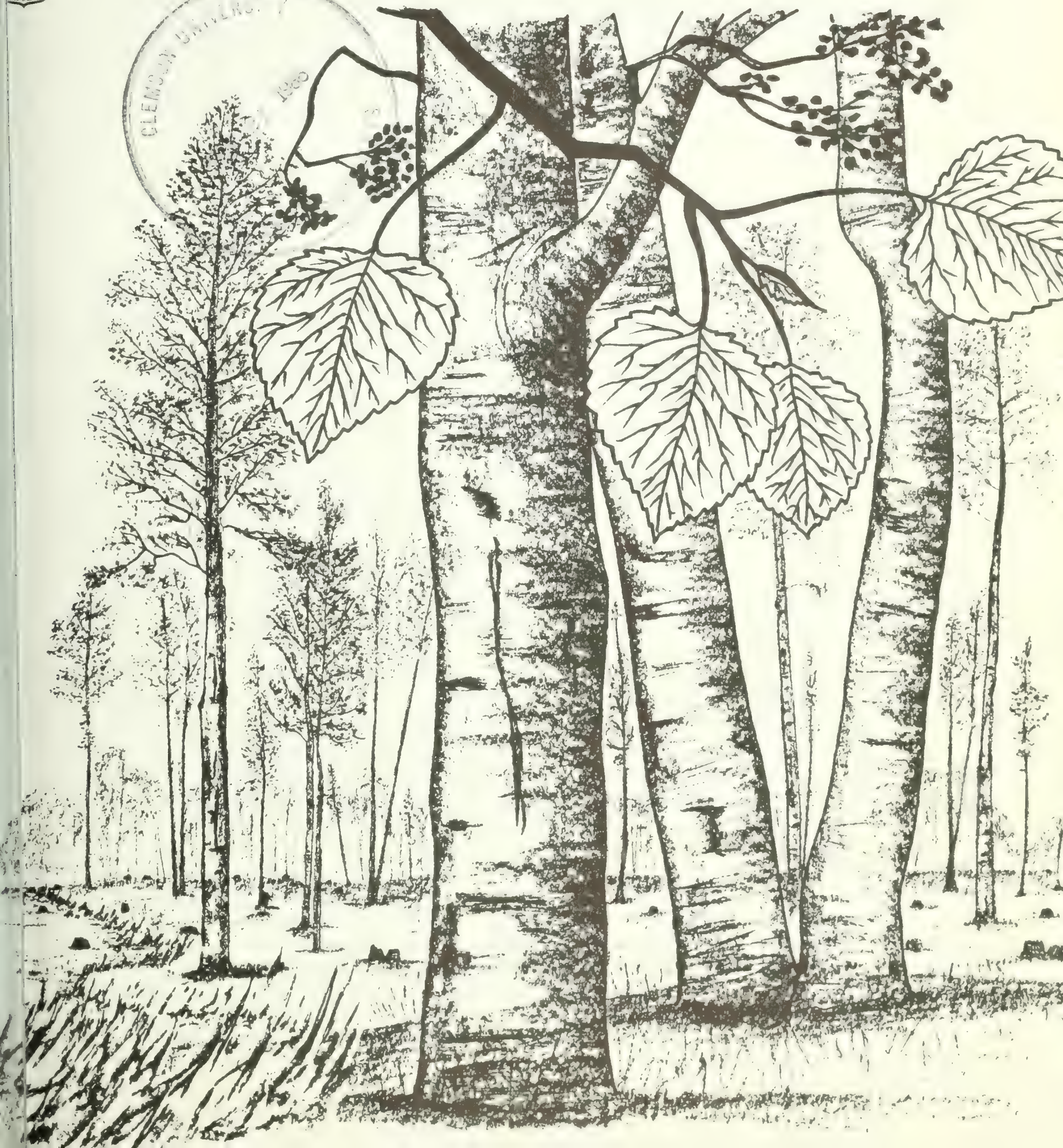
Fire Effects In Northeastern Forests: Aspen

Cary Rouse



PREFACE

This is the first in a series of papers dealing with fire effects in northeastern forests. The 21-State reg incorporates many diverse ecosystems—the northern hardwoods of New England, the boreal forests of Min sota, the oak-hickory forests of Missouri, and fine hardwoods in the Central States. Although some things common to all forests, each responds somewhat differently to fire. Although less is known about fire ecol in the Northeast than in any other region of the country, there is a small body of information scatte throughout the literature. The purpose of this series is to compile what we know today and make it reac available to managers. Each paper in the series will summarize the literature; detailed information on spec topics can be obtained from the accompanying references. When the series is complete in several years, individual papers will be updated and republished as a single, bound volume.

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FIRE EFFECTS IN NORTHEASTERN FORESTS: ASPEN

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". . . almost every forest climax of North America displays a fire subclimax . . ." (17).

spen is Important

Quaking aspen (*Populus tremuloides*) is the most widely distributed tree species in North America (13). Bigtooth aspen (*P. grandidentata*), although not as widespread, is likewise an important species (18). The aspen commercial timber type, consisting of both quaking and bigtooth, is important in the northeastern quarter of the United States. In the Lake States alone, 41 industrial plants used 2 million cords of aspen in 1981 (4). Although much aspen is used, a tremendous amount is still on the stump. In Michigan, the amount of aspen biomass is second only to that of the maple group (30).

servations Not antified

Although fire has been prevalent in the East since before settlement, little has been written about its role in hardwoods. As long ago as 1930, it was noted that although available literature generally described immediate postfire effects, it did not quantify them (14). Further, most fire effects literature lacks prefire vegetation documentation (37). Without this information, real comparisons among fires become questionable.[1] Our purpose here is to bring together existing information about the effects of fire on the aspen timber type in the eastern United States and to suggest silvicultural uses of fire in this type.

NATURAL FIRE CYCLE

"The search for stable communities that might develop without fire is futile and avoids the real challenge of understanding nature on her own terms" (19).

ie Interval

Fire intervals for many areas in the eastern aspen range have been estimated from fire scars, fire reports, and lake sediments (44). Natural fire rotation periods range from 26 to 100 years (19, 44). During presettlement, " . . . large acreages burned at rather long intervals when weather and fuels combined to create peak burning conditions" (20). Presettlement fires probably occurred most often in the fall because forest fuels, including those under bigtooth aspen stands, are more prone to burn in the fall than at any other time of the year (27).

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[1]*In order to compare fires readily, the fire intensity (the product of the available fuel energy and the rate of spread) must be known (7). The intensity of a flaming front can be determined from the actual flame length. The flame length as well as the rate of spread can also give an approximation of heat released. Methods to estimate both rate of spread and flame length in the field without instruments have been devised (34).*

Aspen and Fire

Many large upland ridges that burned frequently or intensely are now domina by aspen (20). It has been hypothesized that on repeatedly burned areas, plant communities, in order to maintain themselves, may have evolved to be more flammable than plant communities on less frequently burned areas (29). The aspen community might fit in this category. It is not very flammable when you (32) and has even been advocated for use in fuel breaks (12). However, once as- pen starts to break up, fuel builds up (45). If this fuel dries, it will easily burn. Smaller material, especially, can become airborne even at low windspeeds and travel great distances while still smoldering. Thus, the fire can be spread quickly, enhancing an entire stand's propensity to burn. Most eastern aspen stands of today originated from destructive logging practices and large, severe fires of the logging/settlement era (6, 16). Repeated fires killed young pine tree and destroyed what pine seed was left while the aspen continued to sprout (16)

FIRE EFFECTS

"Fire is not a perturbation or a disturbance, but a recycling agent and an ecosys- tem stabilizer" (43).

Lethal Temperature

Fire can injure or kill the cambium, buds, and leaves of aspen trees. When livi tissue reaches 147°F, death occurs almost instantaneously (6). Although this is an upper limit, death of plant tissue is a function of temperature and time. Fo example, the cambium layer exposed to 120°F for more than one hour will be killed (6). To produce such temperatures at the cambium layer, there must, of course, be more heat or a longer heating time at the bark surface.

Root Survival

Most fires in the Northeast do not kill the entire aspen tree—both above and below ground. In aspen stands, low intensity surface wildfires are most comm (22). Severe fires may kill the aerial portions of a tree, but leave the roots inta (22). Although root tissue is more susceptible to heat-induced mortality than above ground tissue (23), the insulating quality of the soil and the heat releas characteristics of most fires allow roots to remain viable (22). In contrast, cure slash piles ("activity fuels") may burn so intensely that aspen sucker growth i reduced (31). The main fire adaptive trait of aspen, in fact, is its ability to spr from roots. Aspen roots can range in depth from about 39 to 60 inches but mo sprouts are produced from roots that are within 3 to 4 inches of the soil surfac (13). Lateral roots of aspen may be 80 feet long enabling sprouts to occur at so distance from the parent (18). More commonly, however, new sprouts are with 30 feet of the parent (31).

Factors

Several factors that determine direct fire-caused injury or mortality in an asp tree are: season, bark characteristics, size, vigor, form and clone of tree, and f intensity.

Winter

During winter, most trees are dormant and therefore less susceptible to injury fire (15). In addition, ambient air temperature is lower than at other times of

year, requiring higher energy release rates (i.e., more intense fire) to raise the internal temperature of the tree to the lethal level (6).

rk

Bark insulates and protects the cambium of the tree. Differences in bark characteristics determine the amount of protection the tree has from a fire. Bark characteristics are determined by the age and vigor of the tree. The easiest characteristic to measure is thickness. Although the older the tree the thicker the bark, aspen has thin bark at any age, making it susceptible to fire-induced injury and mortality (39).

e Diameter

Most large trees can usually withstand the same temperature directed at the same sized area better than smaller trees (26, 38, 40) because they have more cambium that can continue to function if a portion is killed. Also, with age, the tree's insulating bark thickens.

or

Aspen of low vigor (e.g., those that have been burned or defoliated repeatedly or are growing on poor sites) do not sprout well and may not be able to heal as quickly as more vigorous trees after they have been injured by fire (9).

rm

The form of the tree is also important in determining the extent of damage. If a tree is crooked or leaning, the flames may be directly below the stem, thereby increasing heat at the bark surface (38). The growth characteristics of aspen, however, usually make for a straight-boled tree (18) if it is undamaged by insects, diseases, storms, or past wildfires.

nes

Some characteristics differ greatly among clones (16). In the West it was found that although most clones sprouted more vigorously after a fire than in a similar unburned area, some did not (3). Although aspen in the West lives longer and grows slower than that in the East (3), different clones probably respond to fires in different ways in the East as well.

e Intensity

Fire intensity is markedly different from fire to fire and even within a fire (31). The greater the fire intensity the more energy is directed at the tree and the greater the likelihood of injury (22). Although low intensity burns may only kill part of the aspen overstory, burns of moderate intensity may kill all the aspen in the canopy (22).

ondary Effects

The direct loss due to fire may be but a small percentage of the trees lost later to disease. For example, *Armillaria mellea* may attack weakened aspen (5). In addition, fires after the establishment of an aspen stand may reduce site index by 6 to 25 feet due to retarded height growth (41). Early stand senility and breakup may also result from fire due to mechanical injury and/or attacks by insects and diseases that physically weaken trees (41). And fire may increase the likelihood that some tree species will frost crack (25). This may be true for aspen, especially since other weather-related mechanical injuries (e.g., sunscald) are common (16).

Growth Stimulations

In some instances, fire may stimulate the growth of aspen trees, as reflected b increases in height, diameter, and/or number of trees. In Canada, a stand orig nally containing no aspen had nearly 4,800 aspen stems per acre after logging and burning (36). In Minnesota, fall burning stimulated aspen suckering (34, Soil heat was found to be the key to aspen sprouting (44).

Temperature and Light

Increased temperature and light after a fire increase aspen sprouting (35, 31). The removal of insulating litter and vegetation as well as the blackening of th soil surface may alter the temperature of the soil for some time after a fire (2) the summer, burned areas are hotter than unburned adjacent areas, but in wi ter, they are colder. The effects of temperature differ with types of soil (2). For example, water infiltration rates in some soils are decreased after burning, increased in others (2). For aspen to produce root sprouts, soil temperature at th roots must be 64°F to 95°F (28). Fire can increase the amount of light reaching the forest floor through destruction of the overstory. During the growing seaso however, the period of increased light is short because herbaceous growth ofte quickly fills in the open places (9).

Associated Vegetation

After most fires in aspen stands, herbaceous growth increases. Invading grass and weeds fill in and ". . .appear to prevent optimum stand development" (41). Repeated burns stimulate hardwood and shrub sprouts (*Quercus* spp., *Corylus* spp. and *Cornus* spp.) (32, 9). If jack pine is present it will also often seed in a a fire (2), as will paper birch, pin cherry, and mountain ash (1). Hazel may do nate sites after fire due to deer browsing other species (1).

MANAGEMENT IMPLICATIONS

"Fire is one of the oldest tools of man, and one of the most powerful (10)."

Regeneration

Aspen regeneration is readily obtained in even-aged stands provided the aspe not decadent (33). The sprout aspen stands that originated after earlier pine l ging and sweeping wildfires are now deteriorating (16). Without a concentrate effort to regenerate aspen, pine and/or slower growing hardwoods or brush wil occupy these sites (33). After a final harvest cut, a prescribed fire can be a " . . . great aid to the establishment of the aspen type" (41). Fire helps insure adequate temperatures for aspen root suckers which are more effective in rege erating a stand than seedlings (33). Although natural regeneration by seed is possible after a fire (46), the seeds require an open but moist seedbed (33). Fir often produce open seed beds but rarely moist ones. To establish aspen regene tion, prescribed fire can be used after logging to kill all remaining aspen (9, 3 although this is not a widespread practice. If the objective is not accomplished second prescribed fire, 2 to 3 years after the first should be used, if enough fu remains.

Timber Stand Improvements

Fire will favor aspen over seed-reproducing conifers (1). Thus, if a change in s cies composition from conifers to aspen is desired, prescribed fire can be used. Usually, any fire in an established aspen stand will damage the aspen crop tr

and should be discouraged (41, 22). If a thinning is needed, it should be done manually, mechanically, or chemically (33).

tegrated Pest anagement

Aspen is susceptible to many fungi that cause cankers and root rots (11, 21). Burning can change insect populations, especially when insects are overwintering in the duff. For example, cut worms in destructive numbers may inhabit leaf litter (16); removing the litter (by fire) virtually eradicates these insects. To date, however, little work has been done on the effect of fire on insects and diseases in this region.

CONCLUSIONS

and Establishment

The best use of prescribed fire in the aspen type is either to establish a new stand after cutting or to regulate an unmerchantable stand. Almost any fire in an established aspen stand is detrimental to silvicultural goals, but it may further other goals such as wildlife-species diversity.

and Rejuvenation

It has been suggested that "if a forest is not going to be completely regulated by logging and silviculture, then presumably natural regulating forces must be allowed some free rein. . ." (42). In aspen, this means stands that are nearly decadent and cannot be harvested due to poor access, poor markets, or other reasons. Others are more blunt, recommending that "if a mature forest cannot be harvested then fire may be one way to establish a valuable new forest in its place" (24). Burning may avoid "silvicultural slums." Aspen stands of the East are rapidly becoming such "slums."

arriers

The greatest physical deterrent to rapid expansion of prescribed burning in the aspen region is the limited number of days when fire weather is suitable for burning aspen (8, 31). There are also attitudinal obstacles: remembrance of infrequent but terribly destructive fires; an organizational bias towards control rather than prescribed fire use; and the widespread acceptance of other silviculture techniques (chemical and mechanical), even though they are more expensive (8). Without disturbance, aspen—"the phoenix tree" (16)—cannot reproduce and will be replaced by other species (35, 33, 16, 18). Fire provides such disturbance.

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Fire has been a natural component of the aspen ecosystem. Any fire in an established aspen stand will cause injury. Aspen is easily top-killed but the roots remain viable. A fire's heat can stimulate sprout growth from these roots, aiding natural regeneration.

KEY WORDS: Fire ecology, fire management, silviculture.

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NORTH CENTRAL

FOREST

EXPERIMENT STATION

20th Anniversary

United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report **NC-103**

Insect Suppression in Eastern Region National Forests: 1930-1980

Richard F. Fowler, Louis F. Wilson, and Donna M. Paananen

FRONT COVER PHOTOS (FROM TOP RIGHT COUNTERCLOCKWISE)

Early tank truck used in the East. Water was pumped from a stream and then taken to treatment site to mix with chemical.

Chemical spraying application with hand sprayer to control white pine weevil on Norway spruce in the Allegheny National Forest.

The Bell 47 helicopter used in forest spraying. Helicopters may be the most used aircraft for insect suppression in the future.

(CENTER) European pine sawfly colony on Scotch pine.

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INSECT SUPPRESSION IN EASTERN REGION NATIONAL FORESTS: 1930-1980

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OVERVIEW

> Next to the earth itself the forest is the most useful servant of man. Not only does it sustain and regulate the streams, moderate the winds, and beautify the land, but it also supplies wood, the most widely used of all materials. Its uses are numberless, and the demands which are made upon it by mankind are numberless also. It is essential to the well-being of mankind that these demands should be met. They must be met steadily, fully, and at the right time if the forest is to give its best service (Pinchot 1905).

Suppressing insect populations and preventing nage by them are integral parts of forest protec- n and management. We report here a history of use of various insecticides and the effectiveness these insecticides against a number of insects in natural timber stands and plantations of the stern Region national forests. Also included are mples of silvicultural and cultural control prac- es.

his report documents the insect species needing atment, the various treatments used, the suppres- n results obtained, and the national forests in- ved. We gleaned the information from numerous nos, letters, worksheets, maps, reports, and other uments in the files of the National Archives, Re- nal Record Centers, and a number of Regional offices. The documents recovered span more than 50 years and although some of the information we had hoped to find was unobtainable, the story is reasonably unbroken and accurate. A few "old timers," who lived part of the early history, reviewed and "corrected" early versions of the report and supplemented missing information from recall.

The Eastern Region and Overall Insecticide Use

The Eastern Region (Region 9, R-9) as it exists today was organized on March 1, 1966, when the former Region 7 (R-7) was abolished. Most of the States in the former Eastern Region (R-7) were incorporated into the North Central Region (R-9) and the Region was renamed (fig. 1). The remainder of the R-7 States were incorporated into the Southern Region (Region 8). To search for records most efficiently, we needed to be aware of our Region's development and various shifts in headquarters' locations. Future Region 9 researchers will need this information also. For that reason, a more detailed history of the development of the Eastern Region is provided in appendix I.

The Eastern Region currently comprises 20 States and is bounded by Maine and Maryland on the East Coast and Minnesota and Missouri in the Midwest (fig. 1). Geographic subregions of Region 9 are the Lake States, Midlands, Northern Appalachia, and New England. The Forest Service administers more

Figure 1.—*Eastern Region (Region 9) national forests by subregions, 1966-1980. Cities named are Forest Supervisors' headquarters.*

than 11 million acres in the Region's 16 forests (table 1). The remaining 10 million acres of land within the forest boundaries are owned by private individuals, industry, and State or local governments. Although acreages discussed in this history may once have been located in another forest or under another name, we have included them with the national forest in which they are now located. (See appendix I for acquisition details.)

During the half century covered by this history, if each of the 390,000 insecticide-treated acres had received only one application, then about 3.4 percent of Federal land would have received treatment (table 1). However, during the 50 years of this study, a number of acres included on table 1 were treated more than once, so the acres shown here (and thus the percentages) are higher than the actual Eastern Region national forest acres treated.

Of the four geographic subregions, the national forests in the Lake States have received the most attention during the period studied. About 367,000 Lake States' acres were treated with insecticides to suppress specific pests, and 9,400 acres received experimental insecticide treatments. Chemicals were applied on about 5.4 percent of the 7 million Lake States acres. Over the same period, 0.4 of the Midlands, <0.1 of the Northern Appalachian, and 0.5 percent of the New England national forest acres received suppression and/or experimental treatment, but lack of some documents from what was once Region 7 prevents exact figures of some acreages.

Insecticide Use

Five types of insecticides—inorganic compounds, botanicals, chlorinated hydrocarbons, organophosphates, and carbamates—were applied to Eastern Region national forests in the 50 years of this study (table 2). (As in table 1, acres shown include those treated more than once during the 50 years of this study.) In addition, unspecified insecticides in unknown quantities were applied on about 30,000 acres from 1937 to 1951 (from 1937 to 1942 most

able 1.—*Eastern Region national forest acreages by subregions and acres treated with insecticides for suppression and experimental testing from 1930—1980*

National forest[a]	Forest acreage[b]	Acres treated for[c] Suppression	Testing	Total	Percent acres treated[c]
		LAKE STATES			
equamegon	844,515	47,964+	1,000	48,964+	5.8+
ippewa	660,959	27,614+	224	27,838+	4.2+
iwatha	880,722	46,835	15	46,850	5.3
ron	414,022	10,433+	347	10,780+	2.6+
nistee	506,533	80,997+	4,530+	85,527+	16.9+
olet	654,025	56,020+	2,425	58,445+	8.9+
awa	924,537	12,050	312	12,362	1.3
perior	2,045,567	84,958	570+	85,528+	4.2+
ubtotal	6,930,880	366,871+	9,423+	376,294+	5.4+
		MIDLANDS			
osier	185,127	12	0	12	< 0.1
rk Twain	1,447,849	268+	0	268+	< 0.1+
iwnee	252,810	6,553+	951+	7,504+	3.0+
ubtotal	1,885,786	6,833+	951+	7,784+	0.4+
		NORTHERN APPALACHIA			
gheny	508,674	262+	385	647+	0.1+
iongahela	842,106	25	0	25	<0.1+
/ne	174,641	215+	0	215+	0.1+
ubtotal	1,525,421	502+	385	887+	<0.1+
		NEW ENGLAND			
en Mountain	279,374	4,719	0	4,719	1.7
te Mountain	728,092	437	0	437	<0.1
ubtotal	1,007,466	5,156	0	5,156	0.5
onal total	11,349,553	379,362+	10,759+	390,121+	3.4+

[a]Names given are current names. Name changes and/or combining of Forests sometimes occurred after initial establishment (see appendix I).
[b]Forest acreages are as of September 30, 1980 (USDA 1981).
[c]Plus sign (+) represents additional incompletely documented acreage treated.

es were probably sprayed with the inorganic compounds lead arsenate and/or sodium arsenate; from 1945 to 1951 the unspecified insecticide was probably DDT).

norganic compounds were used mainly in the 1930's and early 1940's; lead and sodium arsenate were applied on the most acres. Such compounds were subsequently replaced in the mid-1940's by the less expensive and generally more effective chlorinated hydrocarbons.

otanicals are derived from plant parts containing natural insecticides. The only use of a true botanical, nicotine sulphate, was in 1939. Resmethrin,[1] a synthetic reproduction of a botanical insecticide, was used in an experiment in 1973.

Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.

Chlorinated hydrocarbons, which came on the market at the end of World War II, generally replaced the inorganic compounds and early botanicals in forest insect suppression. DDT was the most widely used of this group: more than 265,000 pounds were used on more than 279,000 acres from 1945 to 1964. It was inexpensive, easy to handle, and had many desirable insecticidal properties; however, its use in the national forests was curtailed in the 1960's when undesirable side effects became apparent. Because DDT was effective against many species of insects, it was the standard against which the effectiveness of newer insecticides was measured. In 1964, the last year of its application, DDT was used only for such comparisons.

Organophosphates and carbamates, recent additions to forest spray programs, replaced the chlorinated hydrocarbons in the late 1960's. Although

Table 2.—*Insecticides and amounts applied to acreages of Eastern Regional national forests, 1930-1980*

Insecticide	Years applied[a]	Amount used (lbs)[b]	Acres treated[b]
		INORGANIC COMPOUNDS	
Lead arsenate	1934-1958	5,706+	31,588+[c]
Calcium arsenate	1934	—	1
Sodium arsenate	1936-1939	—	18,693
Copper sulphate	1937	—	4,719
Arsenicals (unidentified)	1938	—	140
Sodium fluosilicate	1948	—	415
Ammonium sulphate	1949	—	30
Lime sulphur	1954	—	28
		BOTANICALS	
Nicotine sulphate	1939	—	830[c]
Resmethrin	1973	1	30
		CHLORINATED HYDROCARBONS	
DDT	1945-1964	265,101+	279,360+
Chlordane	1949	195	1,298
Lindane	1958-1966	57+	116+
Aldrin	1960-1967	1,577+	12,590
Orthodichlorobenzene	1960	—	12
Benzene hexachloride	1965-1967	25+	72+
		ORGANOPHOSPHATES	
Phorate	1959	40	20
Malathion	1959-1976	6,513+	7,878+
Naled	1960	—	14
Dimethoate	1964	8	15
		CARBAMATES	
Mexacarbate	1964-1973	135	545
Aminocarb	1968	75	500
Carbaryl	1966-1974	997+	1,082+
		UNSPECIFIED	
Unspecified	1937-1951	—	30,145+
		Regional total	390,121+

[a]Insecticide was not necessarily used every year during multiple-year periods.

[b]Plus sign (+) represents additional, incompletely documented acreage treated. Dash (—) indicates no data available; source documents were incomplete.

[c]Jack pine sawfly was treated on portions of 300 Manistee acres either with lead arsenate or nicotine sulphate alone or an unspecified mixture of them. In this table, we show that 150 acres were treated with each chemical.

organophosphates and carbamates are generally more expensive than the insecticides used earlier, they control pests through lower dosages.

Figure 2 (centerfold) shows by year the number of acres receiving chemical treatment in the Eastern Region national forests from 1930 to 1980. DDT was clearly the most used insecticide, particularly in 1962 when 104,300 pounds were applied. Arsenic compounds, the second most used insecticides, were mainly applied in the late 1930's. Next most used was aldrin, a chlorinated hydrocarbon like DDT; it was applied from 1960 to 1967. Malathion was sprayed on the fourth largest number of acres from 1959 to 1976. Finally, we have combined all other insecticides, including those unspecified in various documents, into the "Other" category to complete the pictorial record shown in figure 2.

The number and size of insect suppression projects diminished substantially in the final decade of this history. From 1970 to 1980, about 1,300 acres in five forests received chemical treatments, 31 percent of which was experimental. In 1962 alone, the year when the most insecticides were applied, suppression projects or experiments on nearly 109,000 acres in nine national forests were directed against eight insect species. The acreage involving DDT represented 1.5 percent of the Federal forest land within the nine forests and 1.0 percent of the total Federal acreages in the Region.

Twenty-seven Target Insects

Beginning in 1934, 27 species of insects were treated with insecticides on more than 396,000 acres of Eastern Region national forests (table 3). (Total acres treated here are not actual because simultaneous treatments of insects such as the Saratoga spittlebug and the redheaded pine sawfly are reported twice.) Seventeen defoliator species were the most frequently targeted; nearly 281,000 acres were treated for defoliators during the 50 years. Treatments were also directed against two species of sap-sucking insects on more than 96,000 acres, one root feeder on about 13,000 acres, and four bud and twig borers on more than 1,600 acres. While three species of bark beetles were sprayed on more than 4,800 acres, the spruce beetle was the principal target on more than 2,000 trees throughout a 4,000-acre area. Twelve of the 27 targeted species necessitated suppression treatments on more than 1,000 acres.

In natural stands the treatments were mainly against spruce budworm and jack pine budworm—both defoliators. In plantations, the treatments mainly involved four species: Saratoga spittlebug, redheaded pine sawfly, grasshoppers, and white grubs.

Although tree planting was begun on some national forests in 1911, less than 1,000 acres were planted per year. With the advent of the Civilian Conservation Corps (CCC) and other programs in the 1930's, planting increased considerably, especially in the Lake States. Pests of young plantations soon became troublesome, and suppression was necessary against sawflies starting in 1934, grasshoppers in 1936, and the Saratoga spittlebug in 1945. White grubs began causing much concern in 1929, but were not treated with insecticide until 1960, other than a small experimental treatment with lead and calcium arsenates in 1934.

Throughout the 50 years of this history, the Saratoga spittlebug received the most attention (in six Lake States national forests, appendix II, p. 44); DDT was used exclusively from 1945 until 1964. When DDT use was curtailed, malathion was substituted in all but one of the forests. Effectiveness of insecticidal treatments against the Saratoga spittlebug ranged from 0 percent (in 1945 when 66 acres were experimentally treated with DDT at the rate of 0.5 lbs/acre) to several treatments judged 100 percent using either DDT or malathion.

Spruce budworm was the next most frequently targeted insect; suppression attempts against this insect took place in the Superior National Forest

Authors Fowler and Wilson (pest management and research, respectively) examine redheaded pine sawfly damage on red pine in the Manistee National Forest during a 1970 impact study.

only. In eight applications from 1957 to 1963, aircraft sprayed an average of less than 1 pound of DDT/acre on about 85,000 acres (appendix II, p. 46). The largest single suppression project in the Region occurred in 1962 against the spruce budworm; more than 56,000 acres on 25 separate parcels of land were treated (2.8 percent of the acreage in the Superior National Forest). Treatments using both 0.5 and 1 lb/acre were considered to be 97 percent effective.

Suppression projects on the redheaded pine sawfly covered more than 64,000 acres in 11 national forests (appendix II, p. 47). In 1939, lead arsenate and nicotine sulphate were used in the Manistee to treat the redheaded and jack pine sawflies simultaneously. In the Nicolet in 1948 and 1949, the redheaded pine sawfly and the Saratoga spittlebug were treated simultaneously with DDT. Beginning in 1960, malathion was applied by aircraft, hydraulic sprayer, mistblower, and hand sprayer; the heaviest application rate used was 2 lbs/acre on 200 acres in the Manistee National Forest. Unfortunately, results of these suppression projects were not always available.

The jack pine budworm was treated on six Lake States forests (appendix II, p. 50). DDT again was the principal insecticide used both experimentally and for suppression, generally at a rate of 1 lb/acre; effectiveness ranged from 78 to 98 percent. The highest use was in 1962 when nearly 36,700 acres were aerially treated on the Chippewa and the Hiawatha.

Table 3.—*Target insects and years and acreages treated with insecticides in Eastern Region national forests, 1930-1980*

Target insect[a]		Years treated	Acres treated[b]
	DEFOLIATORS		
Spruce budworm	*Choristoneura fumiferana* (Clemens)	1957-60, 1962-63	84,815
Redheaded pine sawfly	*Neodiprion lecontei* (Fitch)	1934-36, 1938-41, 1945-51, 1953, 1957-60, 1966, 1969-70	64,226+
Jack pine budworm	*Choristoneura pinus* Freeman	1939, 1950-51, 1957, 1959-62, 1964, 1966, 1968	61,392+
Grasshoppers	*Melanoplus* spp.	1936-42, 1948-49	50,706+
Pine tussock moth	*Dasychira pinicola* (Dyar)	1962	8,735
Jack pine sawfly	*Neodiprion pratti banksianae* Rohwer	1939	5,240
Forest tent caterpillar	*Malacosoma disstria* Hübner	1936-38, 1951-52	2,132
Gypsy moth	*Lymantria dispar* (Linnaeus)	1954, 1970, 1972, 1974	1,237
Loblolly pine sawfly	*Neodiprion taedae linearis* Ross	1957, 1965	1,135+
Larch sawfly	*Pristiphora erichsonii* (Hartig)	1940-41, 1948-50, 1959, 1965, 1967	497+
Cherry scallopshell moth	*Hydria prunivora* Ferguson	1974	225
Walkingstick	*Diapheromera femorata* (Say)	1950	210
Redhumped oakworm	*Symmerista canicosta* Franclemont	1973	120
Yellowheaded spruce sawfly	*Pikonema alaskensis* (Rohwer)	1968	61
Virginia pine sawfly	*Neodiprion pratti pratti* (Dyar)	1961-64	29
European pine sawfly	*Neodiprion sertifer* (Geoffroy)	1950, 1966	12+
Fall cankerworm	*Alsophila pometaria* (Harris)	1966	0+
			280,772+
	SAPSUCKERS		
Saratoga spittlebug	*Aphrophora saratogensis* (Fitch)	1945-69, 1976	96,166
Pine tortoise scale	*Toumeyella parvicornis* (Cockerell)	1954	53
			96,219
	ROOT FEEDERS		
White grubs	*Phyllophaga* spp.	1934, 1960-67	12,634
			12,634
	BARK BEETLES		
Spruce beetle	*Dendroctonus rufipennis* (Kirby)	1937	4,719
Black turpentine beetle	*Dendroctonus terebrans* (Olivier)	1960, 1965, 1967	84+
Red turpentine beetle	*Dendroctonus valens* LeConte	1966	20
			4,823
	BUD AND TWIG BORERS		
European pine shoot moth	*Rhyacionia buoliana* (Denis and Schiffermüller)	1951-52, 1957-60, 1962	946
White pine weevil	*Pissodes strobi* (Peck)	1950-51, 1958-59, 1962-63	686+
Pitch pine tip moth	*Rhyacionia rigidana* (Fernald)	1951	4
Nantucket pine tip moth	*Rhyacionia frustrana* (Comstock)	1946-49	2+
			1,638+
			Regional total 396,086+[c]

[a]Most common and scientific names used are those approved by the Entomological Society of America (Werner 1982).

[b]Plus sign (+) indicates additional treated acreages incompletely documented.

[c]The Regional total on this table is higher than Regional totals on tables 1 and 2 because this total reflects the simultaneous treatment of two insects.

Suppression and experimental pesticide applica-ions were also used against 23 other insects (ap-endix II, p. 51). The insects are listed in appendix II, . 51 in descending order of the land area treated ·om 1930 to 1980 and range from grasshoppers nore than 50,000 acres treated mainly with inor-anic compounds) to the fall cankerworm (0+ acres ·eated with the carbamate carbaryl). Results were ot available for a number of the treatments listed ere.

The next section of this history will examine in etail the early years of insect suppression and ex-erimentation in the Eastern Region.

HISTORY OF INSECT SUPPRESSION

In the Beginning . . .

> The forest is threatened by many enemies, of which fire and reckless lumbering are the worst. In the United States sheep grazing and wind come next. Cattle and horses do much less damage than sheep, and snow break is less costly than windfall. Landslides, floods, insects, and fungi are sometimes very harmful.
>
> . . . .
>
> Insects are constantly injuring the forest, just as year by year they bring loss to the farm. Occasionally their ravages attain enormous proportions. Thus a worm, which afterwards develops into a sawfly, has since 1882 killed nearly every full-grown Larch in the Adirondacks by eating away the leaves. Even the small and vigorous Larches do not escape altogether from these attacks. Conifers, such as the Larch and Spruce, are much more likely to suffer from the attacks of insects than broadleaf trees. About the year 1876 small bark beetles began to kill the mature Spruce trees in the Adirondacks, and ten years later, when the worst of the attack was past, the forest was practically deprived of all its largest Spruces. This pest is still at work in northern New Hampshire and in Maine (Pinchot 1903).

Before 1900, entomologists thought of forest insects in North America mostly as pests of shade and ornamental trees. Our vast continental forests supplied ample wood products, and forest entomology as a practice was unknown and completely unnecessary. Then in the early 1900's the emphasis shifted (Graham 1929). Conscientious foresters, newly skilled in forest management practices, became concerned about insect-injured and dying trees on their land and sought out forest insect investigators. Entomologists, who for the most part were studying insects as scientific curiosities, responded and soon began studying the biologies of forest insects to learn how to control them.

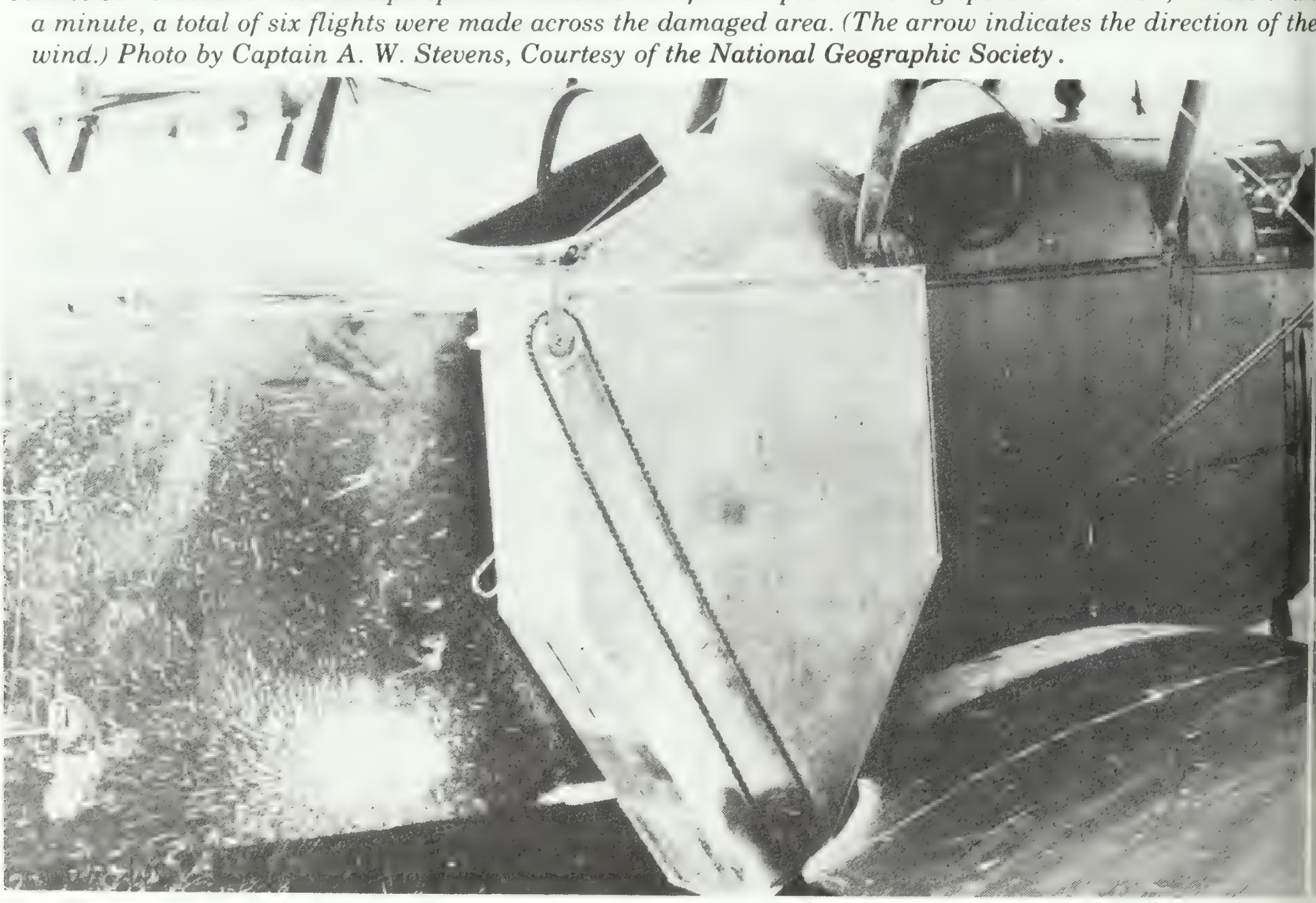
The Division of Forest Insect Investigations of the Bureau of Entomology and Plant Quarantine (BE&PQ) was established in 1902 to act ". . . as the clearing house for advice on when and where control measures should be undertaken on the national forests . . . and [maintain] a technical service for examining reported outbreaks and for giving advice on the application of control" (Gill and Dowling 1943).

For years, the Bureau was mainly concerned with bark beetle (*Dendroctonus* spp.) control projects starting in the West in 1906 and in the South during 1914 and 1915. Control methods used were combinations of felling infested trees, bucking them into short lengths, peeling the bark, and/or burning them. Craighead and Middleton (1930) estimated that bark beetles annually destroyed ". . . over 6,000,000,000 feet of timber valued at from $15,000,000 to $20,000,000."

Because in the East ". . . forests are mainly second growth and direct control methods are, as a rule, too expensive," forest insect investigations were ". . . closely tied in with those of the forest experiment stations in an effort to prevent insect outbreaks through silvicultural practices . . ." (Gill and Dowling 1943). Because "cooperation with the Forest Service experiment stations [formed] another important line of [Bureau] activities," a few entomologists were ". . . stationed at, or in close touch with, . . . the Lake States Forest Experiment Station, St. Paul, Minnesota, [and] the Northeastern Forest Experiment Station, Amherst, Massachusetts . . ." (Craighead and Middleton 1930). These professionals assisted with insect surveys or followed up verbal reports of insect outbreaks in the East.

While silvicultural methods of insect control predominated in Eastern Region national forests before 1930, chemical control was also considered. "Shafer in 1915 published his pioneer work, 'How Contact Insecticides Kill,' . . . which did much to whet [entomologists'] appetites to learn more of the mechanisms of insecticide intoxication to insects . . ."

Curtiss JN-6 used to treat catalpa sphinx in the world's first airplane dusting operation in 1921; in less than a minute, a total of six flights were made across the damaged area. (The arrow indicates the direction of the wind.) Photo by Captain A. W. Stevens, Courtesy of the National Geographic Society.



The hopper with a capacity of 100 pounds that carried and distributed a total of 175 pounds of lead arsenate powder on catalpa sphinx near Troy, Ohio. The hopper was attached to the airplane fuselage. Photo by J. S. Houser, Courtesy of the National Geographic Society.

Loading the Decatur Aircraft Company's biplane with the 200 to 300 pounds of calcium arsenate needed for each flight. Note the operator pouring the dust into the hopper while standing behind the prop blast. Photo by A. A. Granovsky. Courtesy of D. M. Benjamin, University of Wisconsin.

Telford 1967). Even though this book was mainly aimed at nonforestry uses of insecticides, foresters knew that chemicals with known insecticidal properties were potentially useful on forest pests too.

The "usual method of controlling leaf-eating insects affecting tall trees" in the early part of the entury was "by the use of liquid poisons sprayed on he trees by means of engine-driven pumps, these utfits having reached their present development in he New England States in combating the gypsy and rown-tail moths and elm-leaf beetle" (Neillie and Houser 1922). However, in 1921, C. R. Neillie and . S. Houser wanted to overcome some of the difficulties and expense of spraying tall trees, particuarly those situated on very uneven terrain, and hose to experiment with "the airplane as a distribuor of insecticides." On August 3, 1921, "a Curtiss N-6 equipped with a hopper for carrying and liberting the poison powder" applied lead arsenate gainst the catalpa sphinx (*Ceratomia catalpae* Bvd.) n 6 acres at Troy, Ohio, at a rate of 29 lbs/acre. The usting took 54 seconds, "thus establishing a world's ecord for speed in applying insecticides to forest reas," but "the outstanding feature of the applicaon was the remarkable precision with which the oison could be placed at the point intended. . . ." ess than 1 percent of the caterpillers remained alive on the sprayed trees. The conclusion of Neillie and Houser (1922) about the success of the airplane dusting experiment was, "In the treatment of tall trees in park and forest areas the tremendous saving in time and labor in which its use results would seem to indicate that the method is wholly practicable."

Following the dusting in Ohio, "In 1922 the Bureau of Entomology initiated two separate series of experiments in this work; one at the Delta Laboratory, Tallulah, Louisiana, and the other at the Gipsy Moth Laboratory, Melrose Highlands, Massachusetts. The experiments at the Gipsy Moth Laboratory were not conclusive for the first 2 years" (Barnes and Potts 1927).

The next documented airplane dusting experiment in the Eastern Region was in June 1926 in Massachusetts—once again against the gypsy moth. The first application of lead arsenate at 40 lbs/acre on one 25-acre plot took 82 minutes to complete because of mechanical difficulties with the hopper. Three days after dusting, rain fell, so the plot was redusted 8 days after the first treatment. On the total of six plots dusted in this experiment, ". . . the treated plots showed much less defoliation than the untreated checks. . . ." Barnes and Potts (1927) concluded, "Airplane dusting is best adapted for the treatment of large forest areas and its results for the

season of 1926 encourage the hope that this method can be adapted for insect control in such territory."

The next month, a "large-scale" insecticidal control program was initiated against hemlock spanworm, (= hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée)), on State land in Wisconsin (Fracker and Granovsky 1927). Calcium arsenate was applied at the rate of 20 lbs/acre by airplane to 715 acres of the Peninsula State Park in Door County, Wisconsin. Although the treatment gave marginal control by present standards (60 to 95 percent insect mortality), the program continued to convince everyone involved that both chemicals and aircraft could be useful tools in the future.

The Early Years

(1930-1944)

By the 1930's, interest in insect control was increasing in the Eastern Region national forests. Nationwide funding had become available for insect and disease research through the McNary-McSweeny Act of 1928 (Knight and Heikkenen 1980). In 1930, when the Forest Service was 25 years old, several forest pests came under scrutiny by Lake States foresters. At the end of that year, E. W. Tinker, Regional Forester in Milwaukee, submitted to Robert Y. Stuart, the Forester[2] in Washington, an insect control report detailing infestation problems. (The 1930 report is the first regional annual report on insect control available in Eastern Region files.) The jack pine sawfly and engraver beetles, which had killed some jack and red pines, were the major concerns. Also, the jack pine budworm—incorrectly identified as the spruce budworm feeding on pine—caused noticeable defoliation to several jack pine stands. The infestations were not serious enough for control, and a response was not expected from Washington. F. C. Craighead, then Principal Entomologist for the BE&PQ in Washington, was alerted by Assistant Forester E. E. Carter to the report.[3] The white grub received attention in the 1930 annual planting report. In the Chippewa's Beal Nursery, "The greatest damage in the plantation was due to extreme drouth coupled with white grub activity" (Wales 1931).

In 1931, as field observations intensified, more problems were observed in the Lake States. All forest officers were ". . . urged to watch for signs of insect infestation in their respective districts, and to collect and forward samples for identification" (Tinker 1931). That summer the birch skeletonizer (*Bucculatrix canadensisella* Chambers) began an upsurge over thousands of acres in several forests from Minnesota to Michigan. Although more objectionable than damaging, it was especially troublesome to owners of lakeshore and summer homes. Tinker requested from Washington a feasible method of control that he could pass on to summer residents because the Forest Ranger closest to the problem had implied in his report to Tinker that no practical control was known for forest use. Forest Ranger Braudner (1931) had suggested that arsenical dusts or sprays might be used for limited areas around homes.

Of more concern was the injury to newly planted red pines by white grub in the Chippewa and Marquette (Hiawatha) Forests. These injuries, coupled with several successive years of drought, were killing trees. Tinker (1931) wrote, "If damage continues [in the Chippewa], it will probably be well to secure the assignment of an entomologist to study the question specifically." When it was noted that the white grub did not appear to attack natural jack pine reproduction in the Marquette Forest, an experiment was "started to determine whether natural reproduction cannot be secured . . ." to cut down on white grub problems. Foresters piled brush around jack pine trees and set it on fire to kill the trees and at the same time open the cones to scatter the seeds. To learn whether there was any advantage in soil preparation, foresters planned three experiments around the trees to be burned: disking, burning over, and leaving the area untouched (Wales 1932).

Also in 1931, the coarse-writing beetle (*Ips calligraphus* (Germ.)) killed two jack pine trees at the Norways Ranger Station, Raco, Michigan, and nearly 30 more trees died in a sale area nearby. Weakened by drought, the trees attracted the beetles. This episode instigated a control and preventive treatment in which "The trees at the Ranger Station were cut and burned before the insects emerged, so as to check a possibility of epidemic conditions . . ." (Tinker 1931). Although the white grub and coarse-writing beetle treatments were not spectacular control programs, they were appropriate and

[2]*Gifford Pinchot, the first Chief of the Forest Service, had requested that the title "Chief" be changed to "Forester" in 1898. The title Chief was readopted in 1935.*

[3]*Carter, E. E. Assistant Forester, Washington Office. Letter to the R-9 Regional Forester. December 6, 1930.*

timely, and showed a growing concern for insect problems.

By the next year, foresters had become keen observers; they accurately noted that sawfly, spruce budworm, and cone-insect populations were increasing, and the major problem pests from the year before were generally declining. At the Chippewa Nursery, the State Nursery Inspector spotted a pine scale on several large jack pines nearby. Insisting that there was a good chance of infesting the red pine seedlings in the nursery, he recommended that 30 heavily infested trees be cut and burned (Tinker 1932). Effective chemical controls were unknown and untested for the scale, so cultural means were once again marshalled for the job.

By mid-summer of 1932, field crews, now acutely aware of insect problems, were submitting specimens almost weekly for identification. Sometimes specimens were sent to Washington, but more often they went to such experts as the State Entomologist of Minnesota and foresters of the Lake States Forest Experiment Station. In addition, insect specimens routinely went to qualified entomologists at the University of Minnesota, the University of Wisconsin, Michigan State College (now Michigan State University), and the University of Michigan. Samuel A. Graham, Professor of Economic Zoology at the latter institution, participated in the study of forest pest problems of the entire Region.

The election of Franklin D. Roosevelt in November 1932 was to make conservation of our forest resources one of the most important government programs before World War II. According to Steen (1976), in the time between Roosevelt's election and the inauguration, the President-elect ". . . considered combining land acquisition with relief for the unemployed. His staff prepared an $18 million proposal to purchase land east of the Mississippi River, with a like amount appropriated to pay for rehabilitation." Unemployment relief was to come through the Emergency Conservation Work Act (ECW) of 1933, which provided for the Civilian Conservation Corps (CCC). Roosevelt's purchase scheme was closely linked with the CCC because he ". . . wanted 'plenty of land' for the corps to rehabilitate" (Steen 1976). After appropriations of $45 million from 1933 to 1935, nearly 8 million acres were purchased and added to Eastern national forests (Dana 1956). One of the largest projects undertaken by the Corps during its 9 years of existence was reforestation of Lake States forests by planting trees.

In 1932 and 1933, foresters became greatly concerned about insect problems in the newly established plantations. A report of the Region 9 Planting Board of Review noted:

> Forest Service planting has been in progress in the Lake States for nearly

CCC crew from Mormon Creek Camp, Michigan, rehabilitating the Hiawatha National Forest by planting the single tree species red pine, 1939. Large acreages of single or closely related mixed species led to serious insect infestations.

> 25 years. Yet the annual program never exceeded 1,000 acres until about 1926. Since that time it was gradually increased until the advent of the CCC when it received tremendous impetus.
>
> The earlier efforts resulted in several highly satisfactory plantations which appeared to justify an expanded program. During the last few years the percentage of successful plantations appears to have progressively declined, culminating with extremely heavy losses during the past year (Shirley *et al*. 1934).

As 1932 ended, plans were being made to hire an entomologist who would survey the Lake States forests to determine insect conditions and recommend pest control. As a result, Dr. Graham was approached and hired for the summer of 1933 to give "technical assistance" under the auspices of the ECW program (Tinker 1933).

Graham spent much of that summer on the Huron, Superior, and Chippewa National Forests, and, as one might expect with expertise on board, several more insect problems were uncovered. While reporting his findings to the Forest Supervisors that fall, he recommended several immediate cultural treatments.[4] For example, he suggested stopping planting in openings where jack pine budworm was abundant and removing all wolf trees to curb the budworm.[5] The Huron Forest put these recommendations into their management plans for the years following. A weevil attacking the root collars of pine was killing 15- to 20-year-old Scotch pines on the Chippewa, and Graham recommended cutting the infested trees and grubbing out and burning the roots to reduce the trouble.[6] ECW camps on the Superior National Forest concentrated on the spruce budworm to place the forest in a thrifty growing condition. Graham had recommended cutting all balsam fir in release operations for budworm control.[7] This recommendation was readily accepted because most land managers had long considered balsam fir an inferior species to be discriminated against in managing timbered areas. Graham specified no planting in open, sodded fields to prevent losses from the seedling-killing white grub. He suggested using wide, deep furrowing when planting (instead of the narrow furrowing typical of the standard horse-drawn plows).[4] Thus, the necessary expertise had finally come to solve forest insect problems on the national forests—at least in the Lake States.

Most of the cultural practices suggested by Graham were implemented in 1934 and 1935 (Tinker 1935). Efforts concentrated heavily on white grubs, and CCC labor was used for the grub surveys. As a result, some proposed sites were eliminated from the planting program, and seedlings on other sites were planted closer together to allow for the losses. The BE&PQ was "urged to carry forward the white grub studies now under way and to undertake other insect studies within or near the plantations from time to time" (Shirley *et al*. 1934).

In 1934, chemical control was used and documented on Eastern Region national forest land for the first time (Fowler 1973b). In the Manistee National Forest, lead arsenate was tried against the redheaded pine sawfly—an insect that normally can be controlled easily with almost any chemical. A small chemical test (using lead arsenate) was also tried against white grubs in newly established plantations in the Chippewa National Forest (Nagel 1936). Results of the latter were unsatisfactory, however, and the next year Tinker (1935) in his annual report to Washington pessimistically wrote, "It is

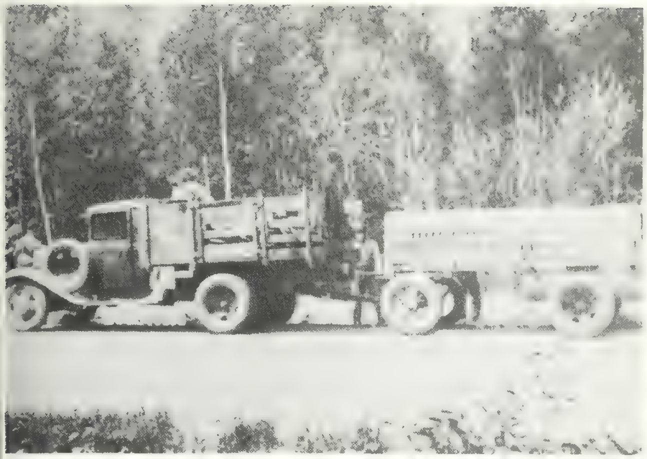
Tractor and plow making wide, deep furrows in an aspen conversion area to prevent losses from seedling-killing white grub in the Chippewa National Forest, 1934. Before the conifer seedlings were planted, their roots were dipped into a lead arsenate suspension. Photo by A. A. Granovsky.

[4] *Graham, S. A. Professor of Economic Zoology, University of Michigan. Memorandum concerning entomological observations on the Huron: August 29, 1933, to September 16, 1933, inclusive. September 30, 1933.*

[5] *Graham, S. A. Memorandum relative to spruce budworm control on the Huron Forest. July 30, 1933.*

[6] *Graham, S. A. Insect situation on the Chippewa Forest. August 14, 1933.*

[7] *Graham, S. A. Insect situation on the Superior Forest. August 28, 1933.*



Truck and hydraulic sprayer used in forest tent caterpillar control in the Superior National Forest in June 1936.

apparent that the possibility of finding a satisfactory chemical for use in grub control . . . is rather remote."

The redheaded pine sawfly continued to get attention the next year. This pest had started injuring trees in 1930; by 1935 it was abundant and was devastating pine in the Lake States. Regional Forester Tinker (1935) suggested that hand dusters or hand sprayers would be useful in chemical control of the sawfly because the trees affected were small. He noted, "Spraying was attempted on a small scale on the Huron this year, but the work was not started until the larvae were nearly mature, with the result that it was not very satisfactory." Undaunted, he added, "It seems highly desirable that control work be done next year, both on the Manistee and the Huron, and plans are being made to do so."

Spray-consciousness broadened in 1935. Chemicals were considered for other insects—including the forest tent caterpillar, which by then had defoliated more than one-half million acres of aspen and birch. This nuisance was discouraging tourists and threatening the recreational economy. Resort owners demanded help in controlling this pest. Surveys indicated that caterpillars would increase tremendously the next year, so plans were made to treat a total of 4,000 acres in 80 resorts. In the Region 9 annual report, Tinker (1935) wrote that hydraulic sprayers mounted on trucks would be efficient for spraying trees with lead arsenate. In addition, he noted that dusting with lead arsenate by an autogyro had been suggested. Tinker stated that while the autogyro would be faster and cheaper than power spraying, it was less reliable, although it had ". . . the advantage of being usable in places inaccessible by trucks." His annual report stipulated:

Spraying aspen for forest tent caterpillar in 1936. (Hose is attached to hydraulic sprayer in other photo.)

> Airplane dusting work usually requires about 20 lbs. of poison per acre [by air], but somewhat less should be required in spraying [i.e., by power sprayers on a truck]. At the rate of 20 lbs. per acre we will need about 80,000 lbs. of lead arsenate, which at $200 per ton will cost about $8,000.

Tinker budgeted an extra $455 to purchase 650 gallons of fish-oil sticker to be added to the spray mixture.

Another first occurred in 1935—Forest Service personnel targeted an integrated approach to control the larch sawfly. The infestation was located in a "swamp" near Deer River just east of the Chippewa National Forest. According to Tinker (1935), the outbreak

> . . . has been effectively checked. This has been accomplished by the liberation of parasites, flooding of the swamp, the application of lead arsenate dust,

and by the aid of several very severe rainstorms which occurred during the time the larvae were feeding.

(This lead arsenate application is not included in appendix II because the work did not occur on national forest land.) He later noted that the BE&PQ had arranged to try rearing parasites from cocoons for future control programs.

Tinker's 1935 report further showed that concern for insect problems had spread to the Midlands Subregion because of "a rather severe infestation of the Nantucket pine tip moth" in the Shawnee National Forest. Control by removing the infested tips was tried and found somewhat successful. Additionally, bark beetles (*Ips* and *Dendroctonus* spp.) were controlled on the Clark National Forest (now part of the Mark Twain) by cutting and burning infested trees (Gilmore 1935).

One of the reasons for so many insect infestations during this time was the size of the planting program. According to the R-9 annual planting report, "The enlargement of the older forests and the addition of several new purchase units in the Region during the past three years has raised the size of the annual planting program to 150,000 acres." The planting "Master Plan" called for the reforestation of 3,000,000 denuded acres in the 15 years following (Grapp 1936).

The year 1936 brought the first large-scale control operation in the Region. Three insects were treated with arsenicals, but the insects of the year were various species of grasshoppers (Orr 1936). A severe drought on the Manistee nearly eliminated the grasshoppers' natural food supply, and in desperation they fed on pine seedlings. Millions of grasshoppers were killed when more than 18,000 acres were baited with poisoned bran, but not before the young plantations were severely damaged. Other acres were chemically treated for the forest tent caterpillar (in the Chippewa and Superior) and the red-headed pine sawfly (in the Hiawatha and Manistee). The results of the latter treatments brought a change in philosophy. Chemical control began to prove itself in the Lake States area, and cultural control started to take a "backseat."

During 1936, there was also a great deal of concern over ". . . an outbreak of the spruce barkbeetle on and near the Green Mountain National Forest in Vermont.[8] E. E. Carter, Chief, Division of Timber Management in the Washington Office (WO), recalled that early in the 20th century the ". . . barkbeetle did a very large amount of damage on some townships in western Maine."[8] Something had to be done soon to curb this pest.

In November of 1936, Region 7's Forester was informed by Carter that $1,500 Emergency Relief Administration (ERA) money ("Eradication" Project 5002) had been transferred from Region 1 to Region 7 to start a late spring control operation on the northern division of the Green Mountain Forest. This allotment was increased by $500 from the WO Insect Control Fund "for supplementary supervision, equipment, transportation, and other costs. . . ."[9] Carter suggested that Region 4's successful larval killing method be tried to reduce suppression costs per tree. According to Carter, their method was spraying thin-barked trees (lodgepole pine) "with oil and heating up the bark by fire to the point where insect larvae are killed." Because temperatures of at least 70° F seemed essential for oil penetration, F. C. Craighead, who was in charge of WO Forest Insect Investigations of the BE&PQ, noted that Vermont spring temperatures alone would not make this method feasible.[9]

Insect problems were becoming so obvious to Region 9 field personnel by 1937 that the Region's annual report read like the rogues' gallery (Watts 1937). More than 20 pests were listed on as many hosts from the Lake States, Midlands, and Northern Appalachia Subregions. Chemical control efforts were concentrated on grasshoppers, the forest tent caterpillar, and the larch sawfly. The white pine weevil, which had no known chemical control prescription, was treated by removing and destroying infested leaders.

The Green Mountain National Forest still had its insect problems, and ERA laborers and ECW enrollees scouted to locate bark beetle infestations between January and June of 1937. During this time, the Green Mountain experimented with Region 4's oil heating method against bark beetle larvae, but "due to the relative thickness of the spruce bark it was impossible to secure adequate control by this method and it was abandoned" (Varney 1937). Even though they weren't happy with their experiment, Green Mountain foresters suggested future experiments with "standing-burning" methods of control such as the use of heavier oil, a propane or gasoline torch, or a standard plumber's torch.

[8]*Carter, E. E. Chief, Division of Timber Management, WO. Letter to the R-7 Regional Forester. September 8, 1936.*

[9]*Carter, E. E. Letter to the R-7 Regional Forester. November 14, 1936.*

In June of 1937, Craighead wrote to J. E. Evenden in Idaho as follows:

> The Forest Service have a right nice barkbeetle outbreak on the Green Mountain National Forest in Vermont. This is a spruce area and there are approximately 5,000 trees infested. It was planned to handle it by timber sale but those "uncanny New Englanders" somehow or other got the idea that the trees will be a lot cheaper after they are dead and the Forest Service couldn't get any bids. Consequently they have the bug trees and the green trees still on their hands.[10]

He then asked for the "loan" of one of Evenden's experienced men starting July 1, 1937, because of plans to ". . . use the chemical method of treatment during the summer and other methods through the fall and probably chemical sprays next Spring."[10] The plan was to use copper sulphate in 1937 and to try chemical sprays, principally orthodichlorobenzene and napthalene carried in fuel oils, in the spring of 1938. However, "between July 17 and August 16 [1937] some 260 infested trees were treated with copper sulphate," but ". . . this method did not prove satisfactory, due in part to the overlapping of generations and decadent condition of the trees. . . ."[11] According to the Green Mountain fiscal year (FY) 1938 report, 440 trees (probably including the 260 previously mentioned) were treated by copper sulphate injection on two widely separated areas during the 1937 summer period of sap flow. (A total of 36,420 Federal, State, and private acres were infested.) Concurrent with this chemical treatment, foresters peeled the bark of infested trees. "During late summer and fall, trees were cut and decked for winter burning" (Woodbury and Newman 1938). In Mills Brook, Vermont, where the chemical injections took place, a horse was used to skid 12-foot logs into larger decks for burning. While the Green Mountain report states, "Where practicable infested timber was salvaged," it also notes, "It is felt that burning is the only sure way of obtaining complete killing of all insects."

In addition, the Green Mountain had a European spruce sawfly infestation that year. R. C. Brown, Entomologist in Charge of the BE&PQ, suggested that ". . . no direct control measures such as spraying are feasible in forested areas because of the cost." He felt that the only practical method was the one used on September 17, when 90,000 European parasites, *Dahlbominus fuscipennis* (Zetterstedt), ". . . were liberated at three points within a radius of two miles of Lincoln Village."[12] Because of the increased importance of the sawfly, representatives of the Bureau arranged a conference with representatives from the Canadian Government on November 12. They decided ". . . to enlarge the work on propagating parasites in this country with the idea of increasing the number that may be available for colonization."[13]

On November 15, 1937, the Green Mountain tried a new method to get rid of the spruce beetle—this time experimenting with the explosive fuses Cordeau-Bickford and Primacord, manufactured by the Ensign-Bickford Company primarily for quarrying. Both enclosed TNT in a fabric cord. The fuses, which explode along their length almost instantaneously, were wrapped around both dead and infested green trees. All experiments proved unsatisfactory as reported by the manufacturer:

> Our product, Primacord, was not of sufficient strength to debark even the dead trees, the bark of which is generally very loose. Cordeau-Bickford wound spirally about a tree would remove the bark on dead trees for a distance of about 10 feet up from the ground, but higher on the tree where the bark is generally tight Cordeau would score thru the bark but would fail to peel it. Various methods of application of Cordeau were tried using varying distances between spirals and by running the Cordeau lines perpendicularly on all sides of the tree.[14]

The late 1930's and early 1940's brought shifts in personnel and emphasis. E. W. Tinker, Regional Forester, left Milwaukee to become Assistant Chief

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[10]*Craighead, F. C. Entomologist in Charge, Forest Insect Investigations. Letter to J. E. Evendon. June 1?, 1937.*

[11]*Schaffner, J. V., Jr. Memorandum for Mr. R. C. Brown. November 16, 1937.*

[12]*Brown, R. C. Entomologist in Charge, New Haven, Connecticut. Letter to Mr. Otto G. Koenig, Forest Supervisor, Green Mountain National Forest. September 22, 1937.*

[13]*LeCron, J. D. Assistant to the Secretary, Department of Agriculture, WO. Letter to C. Edward Behre, Secretary, Northeastern Forest Research Council. December 16, 1937.*

[14]*Brandon, J. K. Vice President, the Ensign-Bickford Company. Letter to R. M. Evans, R-7 Regional Forester. December 2, 1937.*

in Washington in 1936. Lyle F. Watts took on Tinker's former responsibilities. Similarly, L. W. Orr, one of the principal entomologists in Region 9, was transferred to the BE&PQ in Washington in 1938 and was replaced by H. J. MacAloney (Watts 1938). Foresters in Region 9 suggested that the Bureau research the jack pine budworm problem because no control method was suitable, but funds were lacking. In 1938, E. E. Carter wrote Regional Forester Watts that it was fortunate that Watts did not ask for an allotment from the limited insect contingency control fund held in Washington ". . . in view of the urgency of the demands on this fund for control work against barkbeetles in several of the western Regions."[15]

A devastating hurricane on September 21, 1938, blew down about 3-billion board feet of timber in New England and brought Congressional appropriations to the White Mountain National Forest in New Hampshire and Maine. The White Mountain received $500,000 for forest fire hazard reduction and Congress appropriated an additional ". . . $5,000,000 for forest-fire-hazard reduction work outside the national forests in New England" (Gill and Dowling 1943). Under the leadership of E. W. Tinker, two major activities were almost immediately undertaken—". . . the protection of the affected area from fire and the salvaging of the hurricane-damaged timber so that owners could recover some of the values that otherwise might be lost to them." Because much of the downed ". . . timber was pine, water storage was used whenever possible to eliminate damage from insects and disease" (Gill and Dowling 1943). (This is a method that Carolus Linnaeus [1707-1778] is said to have recommended in Sweden in the 18th century.)

While the Region 7 annual insect report (CY 1939) did not reflect these activities, it did show that no insect control project had been conducted that year; consequently the Region 7 report was confined to "Percent of Reduction Obtained" (Evans 1940). For example, a survey of the Boydon Brook area of the Green Mountain showed that the number of spruce beetle-infested trees per acre dropped from 80 in 1938 (before treatment) to less than 0.1 in 1939. Entomologists also checked the status of the bark beetle in the blown down spruce on both the White and Green Mountain Forests but found no threatening outbreaks (Evans 1940).

Pressure of research in 1939 and 1940 kept Bureau personnel from making regular visits to the national forests as they had done in previous years. In addition, the reduction in CCC crews because of the upswing of the Nation's economy nearly halted insect surveys. The Bureau therefore sent vials of alcohol to the districts so field personnel could send in specimens as they found them during their routine work (Price 1940).

White pine trees as large as 3 feet in diameter damaged by the 1938 hurricane in New Hampshire. As many logs as possible were stored in ponds to prevent damage from insects and disease. Joseph Kaylor of the USDA Forest Service is standing on a fallen tree.

Hurricane-damaged 65-year-old managed spruce stand in the White Mountain National Forest 1938. No bark beetle outbreaks occurred in the downed spruce.

[15]*Carter, E. E. Letter to L. F. Watts. November 15, 1938.*

The Region 9 annual insect report for 1940 pointed out that research was needed on problems developing from the large-scale planting program of the previous years. The older plantings were being injured by various sawflies and the white pine weevil; and they needed attention and protection (Price 1941). In his annual report for 1940, Regional Forester Price insisted, "This problem is considered so important that a request has been made to the Division of Forest Insects to carry out a study of plantation insects." Consequently, a grandiose study was proposed to devise ". . . silvicultural methods of preventing or limiting serious insect injury to the pine plantations of the Lake States."[16] Optimistically it included research on stand density, site variation, mixed plantings, and insect resistance. Plantation insect research began in 1941 on the Manistee with the Chittenden Nursery, Wellston, Michigan, as headquarters (Price 1942).

During CY 1940, Region 7 undertook two small, direct insect control jobs. One was the spraying of lead arsenate against the larch sawfly in a recreational area on the Allegheny—"Within two days after the treatment all of the insects were dead" (R-7 Forester 1941). The procedure on the second project began with sending CCC crews to scout the spruce beetle on 600 acres of the White Mountain. They located 396 infested trees which, early in 1941, were felled, "cut into short lengths, split, and piled over the stumps together with the brush and set afire" (R-7 Forester 1942).

Region 7's 1940 annual insect control report noted that Forest Service personnel had recognized natural control of an infestation in the vicinity of Peru, Vermont. Even though 15 to 20 percent of the trees in a red pine plantation had been defoliated by the redheaded pine sawfly, few of their cocoons could be found. Instead ". . . there was considerable evidence of their destruction by ground-inhabiting rodents" (R-7 Forester 1941).

Region 9 foresters were confident about their plantation insect research at the end of 1941. Their annual report stated, "Already it is reported that there is evidence that proper management methods will insure a limitation of damage by [plantation] insects." The Regional Forester, however, feared that what had been gained might be lost as the country entered the war. Hence his insistence that "This plantation problem is given first priority rating in connection with national defense and should be carried on without interruption . . ." (Price 1942). The 1941 annual report marked the first discussion of the Saratoga spittlebug. Graham in 1956 recalled that in 1940 this insect was known only in museum collections, but 16 years later, it had become ". . . one of our most serious pests of sapling hard pines."

Assistant Forester Arthur O. Schafer (1942) reported in the annual planting report from the Hiawatha that spring planting was less than usual because of stock shortages. Although the fall season was characterized by an abundance of stock, there was an acute shortage of labor. "Local men are difficult to secure and the quality is very poor being largely those dropped by reduction of W.P.A." Nevertheless, a serious white pine weevil infestation in 485 acres of jack pine was controlled on the Hiawatha—". . . the infested terminals were removed by cutting with pocket knives and the tips burned" (Schafer 1942). That year marked the first recorded chemical treatment on the Wayne—186 acres were hand sprayed with lead arsenate for the redheaded pine sawfly (Fowler 1973a).

The most serious outbreak in Region 7 during 1941 was on the White Mountain where 4,000 acres of maple, beech, and birch were almost completely defoliated by the saddled prominent (*Heterocampa guttivitta* (Walker)). No control work was planned because when J. N. Schaffner of the BE&PQ examined two areas, he found that native predators had already destroyed 59 percent and 91 percent, respectively, of the pupae (R-7 Forester 1942).

During the war years there was a shortage of workers on the forests. Hundreds of thousands of CCC enrollees had answered the call to war in 1941. Congress, concluding that the purposes for which the CCC had been created had been served, eliminated the 9-year-old CCC program in June of 1942 (Guthrie 1943) and there was little concerted effort after that to survey for insects. Planting, although diminished, continued through the efforts of conscientious objectors and prisoners of war who lived in the abandoned CCC camps.

Research continued on plantation pests but concentrated on the Saratoga spittlebug, which had destroyed portions of numerous Region 9 plantings since 1940 (Ochsner 1943, 1944; Secrest 1945), and the larch sawfly, which had been active on the Allegheny since 1940 (R-7 Forester 1943). Control programs dwindled; when needed they were mostly cultural and implemented in cooperation with the Civilian Public Service Corps. The Corps' major control effort was cutting pine tortoise scale-infested

[16]*Anon. 1940 (?) Outline for a proposed ecological study of the pine plantations in the Lake States Region to determine silvicultural methods of preventing serious insect injury.*

trees and either leaving the cut material on the ground (the scales cannot live on the cut material) or burning it (Ochsner 1943, Wales 1945). Because of limited research information, curtailed surveillance, and shortage of materials, no chemical pesticides were applied on national forest lands in 1943 and 1944.

In 1944, Region 7 personnel realized that the spruce budworm was threatening spruce-fir stands on both the White and Green Mountain Forests. Entomologists knew that they had 5 to 10 years in which to prepare for possible epidemic outbreaks. In January of 1945, the Northeastern Forest Experiment Station and Regional Office personnel conducted training sessions for staff from both forests, and they helped draw up a plan of action. This plan contemplated

> . . . a survey to determine areas of high hazard, to direct timber-sale operations into such areas, and [formulated] a program for postwar TSI work in hazard reduction which cannot be handled through commercial sales (Mattoon 1945).

As the early years of chemical insect suppression were coming to a close, entomologists throughout the 20 Northeastern States had time to reflect on the past successes and failures from arsenical applications. By this time more than $3 million had been spent on the control of insect outbreaks in all Federal land, and a proportional amount of this had been used in the Eastern Region (Gill and Dowling 1943).

Besides doing limited research, the Division of Forest Insect Investigations became fully responsible for surveys during the war. With a shortage of personnel and added responsibilities, the Division did what it could, but like other short-handed agencies it tightned its belt and waited out the war.

The DDT Era

(1945-1964)

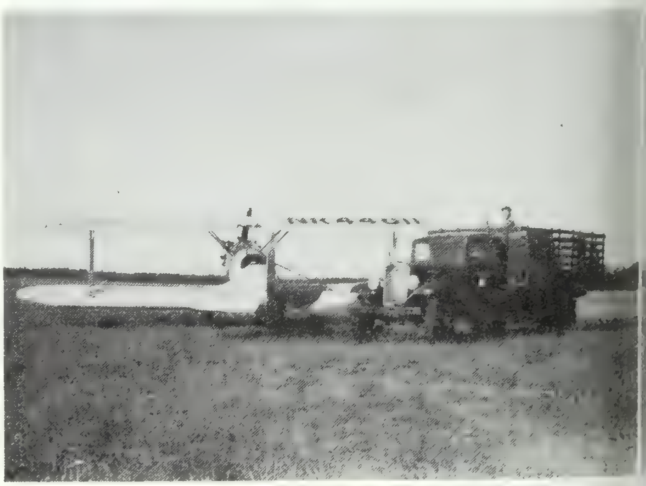
In the history of pesticide usage, the 20-year period after World War II aptly qualifies as its "Golden Age." Paul Müller's discovery of the insecticidal properties of DDT in 1939 and its subsequent success during the War led to its almost immediate testing against forest pests. Because arsenicals were harmful to man and not totally successful as control

N-3-N biplane equipped with a spray dispensing apparatus that was used in the first DDT control operation in Eastern Region national forests in July 1945. The Saratoga spittlebug was treated on 478 acres in the Nicolet National Forest. Photo by H. C. Secrest.

agents, this new chemical was welcome. When the effectiveness of DDT was proven, it became almost the sole panacea for forest pest control.

The Saratoga spittlebug had been the greatest concern in Region 9 since 1940, and researchers concluded in the early 1940's that

> Control through the use of chemicals obviously would not be satisfactory. The adults are sucking insects and a contact insecticide would be necessary. They are extremely active, and any movement of the branches, such as



A hand pump was used to transfer the DDT-oil mixture from the 55-gallon drums located on the bed of the truck to the spray tank of the N-3-N. Photo by H. C. Secrest.

would occur if a forcible spray was being projected against the trees, would be sufficient to cause them to move before the spray would cover them. The nature of the nymphal development, in masses of spittle usually beneath the litter surrounding the root collar of the sweet fern plants, precludes the use of contact sprays such as have been used successfully against the pine spittle bug (Secrest 1944).

After pesticide screening tests on the spittlebug in 1944 found DDT far superior to arsenicals and other chemicals (Anderson 1945, Secrest 1945), large-scale DDT tests followed in 1945 (Sump 1946, Secrest 1946). The first test occurred on July 13 and 14, 1945, when an N-3-N navy trainer plane sprayed DDT at 0.25 to 5 lbs/acre on 478 infested acres on the Nicolet. Shortly after the higher dosages succeeded in the tests, an additional 65 acres were treated on the Ottawa.

In the Nicolet study, the Fisheries and Wildlife Service assisted the BE&PQ's Division of Forest Insect Investigations in determining effects of DDT spraying on wildlife inhabiting the area. They were quoted in the 1945 annual insect report as observing that "no ill effects to any vertebrates were found in the area." The report added, however, that "In one pothole adjacent to the [sprayed] area . . . eight dead frogs were found and in an adjacent lake one small paralyzed garter snake and one dead frog were found." Subsequently, spraying at dosages of 2 lbs/acre or less was recommended. The report further noted the Region's plan to purchase enough DDT to spray 3,000 to 4,000 acres the next year (Sump 1946).

Such DDT tests did not go unnoticed by Forest Service officials in Washington. Only 3 months after the Wisconsin spraying, the Agency demonstrated how cautious it was about the new insecticide. In October of 1945, Lloyd W. Swift, Chief of the Forest Service's Division of Wildlife Management, stated the Forest Service's position on DDT at the 41st Annual Convention of the National Audubon Society. The position statement ". . . was part of a discussion on the use and effect of DDT by Federal, state, municipal, university, and conservation organization representatives. . . ."[17] Swift concluded the statement as follows:

At this time the Forest Service is in no position to define the limits of usefulness of DDT in its work. We intend to consider fully both its advantages and disadvantages under the widely varying conditions which we have to meet. . . . Before its use is fully accepted, the Service would want to know what can be expected under a given set of conditions—what forms of beneficial life, insects, birds, amphibians, fishes, etc. would be endangered and to what extent (Swift 1945). (See appendix III for Swift's complete statement.)

While foresters were testing DDT in Wisconsin in 1945, silvicultural methods predominated in Region 7. There was such a demand for "National Forest stumpage" that stands vulnerable to spruce budworm attacks were reduced through commercial timber sales. As Forester Tabbutt wrote in the 1945 annual report:

The personnel on both the Green and White Mountain National Forests have received training in identifying budworm attacks and are on the alert for new outbreaks of the insect. In the meantime, every reasonable effort will be devoted to placing our spruce-fir stands in the best silvicultural condition to resist attack and minimize damage (Tabbutt 1946).

Similar cultural controls were made against the spruce beetle, the bronze birch borer (*Agrilus anxius* Gory), and beech scale (*Cryptococcus fagisuga* (Lindinger)). In addition, Region 7 arranged to publish and distribute a pamphlet to advise private landowners in New Hampshire and neighboring States about the control of the latter two insects plus the spruce budworm.

Direct control measures initiated in New England forests in 1945 were expanded in 1946. Forester Tabbutt reported:

Scouting and investigative work have been continued in a systematic manner as a means of detecting any new infestations or changes in existing conditions on the ground. Early detection of any "hot spots" that may occur will enable us to initiate such cutting operations as may be desirable, without undue delay. The increasing demands for National Forest stumpage, both softwood and hardwood, are being

[17]*Granger, C. M. Assistant Chief, U.S. Forest Service. Letter to Regional Foresters and Directors. November 16, 1945.*

> utilized to the fullest possible extent to remove mature, overmature and decadent timber and thereby improve the vitality of the residual stands (Tabbutt 1947).

According to available records, Region 7 had yet to use DDT in its national forests.

Forest pests seemed to build up and become more widely distributed in Region 9 during 1946. The redheaded pine sawfly had long been a pest in the Lake States forests and now was breaking out on the Shawnee. In fact, several foresters questioned further planting of pines because of problems in general in plantations. Both the redheaded pine sawfly and Saratoga spittlebug were serious problems, and white pine weevil and Nantucket pine tip moth populations were on the upswing.

DDT in an oil solvent was sprayed by air against the Saratoga spittlebug on more than 2,500 acres in the Nicolet, Ottawa, and Manistee (appendix II, p. 45–46). DDT-oil and DDT-wettable sprays were applied both by air and by hand against the redheaded pine sawfly in the Manistee, Hiawatha, Chequamegon, and Shawnee. In July of 1946, a few lab-reared parasites obtained from the Dominion Parasite Laboratory, Belleville, Ontario, were released against the sawfly in infested areas (Wales 1947).

Region 9's 1946 annual report gave tentative plans for the 1947 control program, which showed a potentially enormous increase in the use of air-applied DDT: ". . . it will probably be necessary to spray approximately 13,800 acres" (4,300 acres of spittlebug and 9,500 acres of sawfly infestations). The Assistant Regional Forester further estimated that the cost of insect control in 1948 might be as high as $30,000 and suggested that such an amount ". . . be earmarked for this work" (Wales 1947).

Because Region 9 was still understaffed after the War, the report concluded by stating that in the past land managers had depended heavily on the BE&PQ's Division of Forest Insect Investigations ". . . but the problem has now become so large that we cannot very well expect that office to handle all of the various phases of work the job entails." The annual report recognized the need for more "Technically-trained personnel, who can spend full time on the job making reconnaissance of infested areas and determining insect abundance. . . ." The report called these personnel ". . . essential to any evaluation of potential damage sufficiently accurate to enable adequate planning for control." The Assistant Regional Forester promised that estimates for FY 1948 would include funding for such a position (Wales 1947).

The year 1947 was, as predicted, the largest spray year in Region 9 since the late 1930's—more than 18,500 acres—but now applications were easier because foresters depended less on hand spraying and more on the biplane. Bids were taken for aerial spraying and low bidders on most of the flying were the Safeway Crop Dusting Company of Decatur, Illinois, and Air-Spray of Eagle River, Wisconsin (Jones 1948). Regional pioneers in DDT and airplane control were H. A. Bess, C. B. Eaton, and D. M. Benjamin.

Airplanes and DDT led to a swan song for arsenicals in 1947. Although more than 2,000 redheaded pine sawfly-infested acres had been hand sprayed with lead arsenate in 1946, only 87 acres (in the Nicolet) were hand sprayed in 1947—possibly from leftover supplies (appendix II, p. 45–46, 47–49).

More than 2,000 acres were aerially sprayed to control the redheaded pine sawfly on the Chequamegon during the summer of 1947. The degree of success using a 1/2 lb/acre DDT mixture ranged from 0 to 50 percent, however, necessitating some respraying by air (using a 1-pound mixture on 75 acres, which was reported to be 100 percent effective) and by hand (using a 1/4-pound mixture on 416 acres, which was 90 to 98 percent effective). Chequamegon's Acting Forest Supervisor Halvorson (1947) reported encountering problems other than initial poor aerial spray results. For example,

> Poor distribution of the spray was encountered soon after the start of the job, due partly it is believed, to wear in the pumping apparatus on the plane, and partly to clogging of the nozzles. . . .
>
> When an attempt was made to use Highway 77 as a landing strip, the plane nosed over, damaging it sufficiently to put it out of commission for a week, delaying the job (Halvorson 1947).

The Shawnee was also sprayed for the sawfly that year, but Bess and Eaton (1948) reported that the control was erratic.

G. W. Jones (1948), Chief, Division of Timber Management, described the aerial treatment of the spittlebug in the Nicolet and Ottawa as "very successful." He reported that inconsistent aerial spraying results against the redheaded pine sawfly "can be attributed to the size of the globules of oil spray as

they struck the trees and insects. . . . Some experimenting which was done using various types of nozzles under different pressures seems to bear out this contention." After experimentation "to determine the minimum effective dosage" to control the sawfly, Bess and Eaton (1948) concluded that 1/2 to 1 pound DDT in 1 gallon of spray per acre was satisfactory. If properly applied under favorable conditions, the lower dosage was ample—"especially if the larvae are not beyond the 4th instar."

While Region 9 was going ahead full throttle with DDT spraying, Region 7 was able to continue applying silvicultural controls. Except for the bronze birch borer, Region 7 had no insect epidemics. An extremely cold winter in 1947-1948 held in check insects like the beech scale (Mattoon 1948).

The Forest Pest Control Act of 1947 (16 U.S.C. Sections 594-1 to 594-5) established a definite pest control policy for all forest land in the United States. It was especially significant because it recognized the need to detect dangerous pests and provide for the control of outbreaks. "The language of the Act [reflected] the enthusiasm for direct, usually chemical, means of pest control" (National Academy of Sciences 1975). It also provided for pest-control cost-sharing—whereby cost of control on privately owned land could, under certain circumstances, be subsidized by Federal funds. The Act further provided funds for insect surveys ". . . to detect and appraise infestations of forest insect pests and tree diseases, to determine the measures which should be applied on such lands . . ." (USDA 1978). Incidentally, there were no direct provisions in the law for research.

As the 1940's neared an end, DDT remained the prevalent insecticide for most forest pests. Foresters had learned that DDT cost less and was generally less toxic than other previously used chemicals, resulting in its becoming overemphasized in the minds of some. In 1948, about 7,500 acres in Region 9 were treated against infestations of the spittlebug (aerial spraying) and redheaded pine sawfly (hand and aerial spraying). Spraying equipment had improved considerably by 1948—the airplanes were better equipped and able to carry larger loads than in the past and were flown by first-rate pilots. One airplane in Region 9 developed engine trouble during spraying, however, and the pilot and plane came down in the trees. The plane was a total loss, but fortunately the pilot escaped serious injury.

Major personnel changes occurred in 1948—Henry A. Bess, head of the Division of Forest Insect Investigations of the BE&PQ went to work in Hawaii and Charles B. Eaton, an entomologist at the Forest Insect Laboratory, Beltsville, Maryland, who had previously worked closely with Bess, took his place as Entomologist in Charge at the Milwaukee Laboratory. Daniel M. Benjamin[18] of the Milwaukee Laboratory was also a major advisor to the Forest Service concerning insect infestations during this period (Jones 1949). Frank C. Craighead retired in 1950 after 30 years of service as head of the Bureau. He was succeeded by James M. Beal.

In 1949, Region 9 experienced insect infestations similar to those in 1948; about 8,700 acres were sprayed with DDT to control the redheaded pine sawfly, larch sawfly, and Saratoga spittlebug.

"Chlordane, the first of the cyclediene insecticides . . ." (Telford 1967), was developed in 1945 and used in 1949 as poison bait to control grasshoppers on nearly 1,300 acres in the Manistee. This treatment, in addition to 30 Hiawatha acres treated with ammonium sulphate, marked the last year that grasshopper control was conducted. In the 1949 annual report the Assistant Regional Forester wrote, "The Region now has two mistblowers, which should permit treating areas up to 100 acres very effectively" (Ochsner 1950). This equipment was a boon to foresters, for while the cost was comparable to spraying by plane, the mistblower could be used when spraying by plane was impractical. Mistblowers were used on 440 acres in the Chequamegon, Hiawatha, and Manistee that year.

In a 1950 letter to division chiefs, W. S. Swingler[19] summarized Region 7's previous 5 years of insect control as follows:

> Practically all pulpwood operations during the past five years have been to salvage the spruce and fir infested with

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[18]*Benjamin and others have published summaries of the insecticide use in Wisconsin forests from 1926 to 1976. Their three University of Wisconsin-Madison Forestry Research Notes are as follows: Daniel M. Benjamin, Donald W. Renlund, and Donald C. Schmiege, "A brief history of the use of insecticides in Wisconsin forests," No. 98, April, 1963; Daniel M. Benjamin, Donald W. Renlund, and Imants Millers, "Insecticide use in Wisconsin forests: 1963-1968," No. 146, April, 1969; and Daniel M. Benjamin and Donald W. Renlund, "Insecticide use in Wisconsin natural forests and plantations: 1969-1976," No. 198, December, 1976. The fourth note in the series, covering 1977 to 1984, is currently being prepared.*

[19]*Swingler, W. S., R-7 Regional Forester. Memo to Division Chiefs. October 9, 1950.*

the spruce budworm and fir bark louse [*Chermes piceae* Ratz.], and to provide resistance to these insects. The cuttings have been made in accordance with the recommendations of entomologists and research silviculturists.

Clearly foresters were polarizing into two factions—those who used silvicultural methods and those who were spraying chemicals. Foresters in Region 7 remained conservative.

The decade of the 1950's was not long underway when the Chief of the Division of Timber Management, Ira J. Mason, wrote to all Regional Foresters as follows:

> Mr. Carter's S-Control, Insect memoranda of December 6, 1932 and September 28, 1939 itemized the data to be submitted to this office on insect control work accomplished annually.
>
> We wish to restate these instructions and bring them up to date with the conditions that now prevail.
>
> The main purpose of the data is to furnish this office with information on accomplishments and expenditures. Narrative is *not* desired, but rather factual data in tabular form.[20]

The 15 main types of data required were to be submitted on a calendar year basis by November 1 of each year and included: control expenditures, percent of reduction obtained, and number of worker days used (in control work) on the project.

The reports in response to Mason's directives from Regional Foresters in Regions 7 and 9 showed that the 1950's, like the late 1940's, were almost totally DDT years. For example, white pine weevil was treated for the first time in Region 9 in May of 1950 when a Bell helicopter sprayed Manistee plantations with DDT-oil solutions. In August of the same year, the walkingstick in the Nicolet was sprayed with DDT by plane—that treatment was the only insecticide treatment ever to be used against the walkingstick in an Eastern Region national forest.

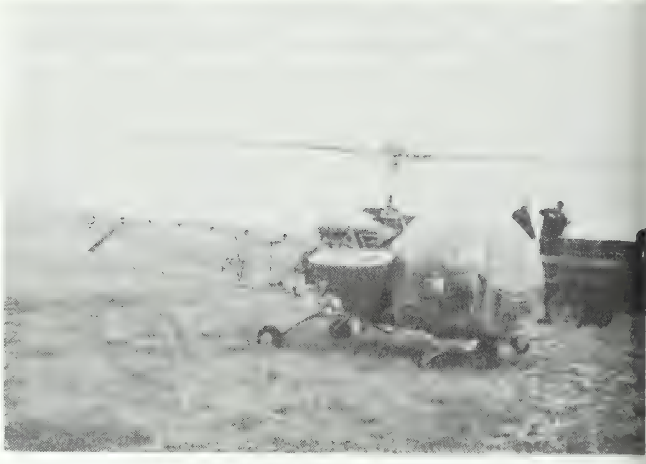
In July of 1951, Region 7 tried helicopter spraying with DDT at 4 gallons per acre on 71 Allegheny acres to control the European pine shoot moth. Although the helicopter pilot did an exceptionally thorough spray job and the spray was applied at the proper time with no wind movement, the results were disappointing. However, McIntyre (1951) stated that a simultaneous knapsack spraying treatment on 235 ornamental red pines (1/4 acre) at 64 gallons per acre was highly successful. He concluded:

> It appears that a large volume of spray is required to effect satisfactory control of [the pine shoot moth]; volumes which would be entirely impractical to apply with helicopters or hydraulic equipment except on small ornamental plantings of high value.

R. C. Brown, Entomologist in the BE&PQ, New Haven, Connecticut, wrote a memorandum to those interested in the control of the pine shoot moth by the use of aircraft:

> It seems to me that the only practical method of combatting the shoot moth problem is to refrain from planting red pine in those areas where the shoot moth can survive low winter temperatures. Our surveys are designed to determine the location of such areas in the Northeast.[21]

One of the recipients of the memorandum, Acting Regional Forester Mattoon (R-7), remarked, "Inasmuch as we have used red pine quite extensively for

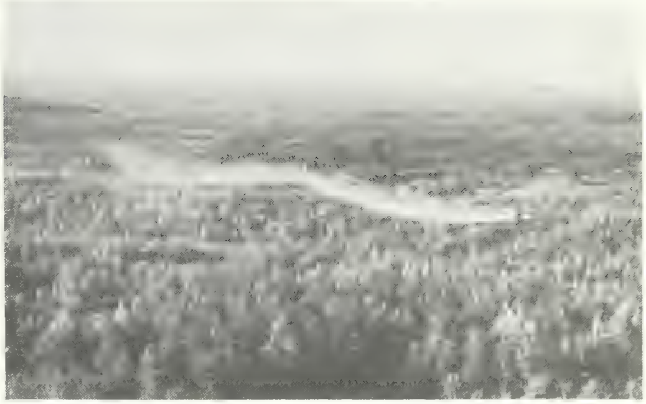


Bell helicopter at loading point taking on 50 gallons of DDT spray for use against the white pine weevil in jack pine plantations in the Manistee National Forest in May 1950.

[20]*Mason, Ira J. Chief, Division of Timber Management. Letter to all Regional Foresters. April 19, 1950.*

[21]*Brown, R. C. Entomologist, New Haven, Connecticut. Memo to Dr. J. A. Beal, Entomologist in Charge, Forest Insect Investigations, Beltsville, Maryland. October 8, 1951.*

Stearman used to treat the walkingstick with DDT. The biplane was fitted with a boom and nozzle attachment beneath the lower wing, and a wind-driven positive displacement pump was mounted on the landing gear. Photo by Charles B. Eaton.



Plane spraying walkingstick-infested hardwood stands in the Menominee Indian Reservation—the treatment was highly successful. Photo by Charles B. Eaton.

lanting and until recently have considered it one of ur most desirable species, we have requested Dr. Brown to keep us advised as to the results of his urveys in this respect."[22]

The shoot moth on the Allegheny attracted much ttention again in July of 1953, when Region 7 reuested $1,000 from the Washington office to ". . . go nto some of the less heavily infested plantations to emove with hand labor the affected branch tips of ome of the trees or remove heavily damaged trees ntirely. There are now 145 acres of known affected ed pine plantations."[23] After much correspondence nd delay (due, in part, to the BE&PQ being low on avel funds), Tom McIntyre of BE&PQ reexamined he plantations sprayed in 1951 and decided that egion 7's suggested control measures were not feable because (1) the trees were too tall for close examination of branch tips and terminal buds;) adequate control required complete eradication ithin a plantation, not partial as was suggested; nd (3) the requested $1,000 would control about 8 or) acres, far short of an effective job. At least temporarily, Allegheny foresters abandoned the plan to radicate" the European pine shoot moth from the rest's plantations.[24]

Although the gypsy moth was first introduced into the country and the Eastern Region in Medford, Massachusetts, in 1869, available records show that it was never chemically treated in any of the 16 Eastern Region national forests until 1954 when it was sprayed with DDT on 410 acres in the White Mountain (appendix II, p. 53). (Although the White Mountain again used chemicals against the gypsy moth in 1970 and 1972, the only documented treatment in another Eastern national forest occurred in 1974 when carbaryl was used on 800 gypsy moth-infested Manistee acres.)

In 1957, the pine shoot moth was again a problem in Region 7 when $750 was requested from Washington to handpick or prune and burn buds in 40 infested Allegheny acres. The Northeastern Station had approved the control method, believing that it "might save an expensive aerial control job later."[25] Similar work was allotted $2,000 for June of 1958.[26] Unfortunately, no existing Region 7 reports confirm that the control work was completed.

The East was not the only area in which entomologists recommended silvicultural controls to prevent damage by insects. In the early years Graham recommended cultural methods, but later he summarized the history of the Lake States forests as one of extremes: (1) rapid and wasteful logging, (2) burning and reburning to keep unsuited forest land open for agriculture, (3) replanting with too much of the same species and age class on contiguous

[22]*Mattoon, M. A. Acting Regional Forester, R-7. Memo to the Chief, Forest Service, WO. October 25, 951.*

[23]*Olson, Roy W. Acting R-7 Regional Forester. Letter to the Chief. July 3, 1953.*

[24]*Costley, R. J. Forest Supervisor, Allegheny National Forest. Memo to the Regional Forester. October 2, 1953.*

[25]*Olson, Roy W. Acting R-7 Regional Forester. Memo to the Chief. June 10, 1957.*

[26]*Olson, Roy W. Acting R-7 Regional Forester. Letter to Supervisor, Allegheny National Forest. April 7, 1958.*

areas, and (4) relying too much on insecticides to control infestations caused by careless planting (Graham 1956). He asserted:

> Far too much reliance is being placed on the effectiveness of insecticidal treatments, because they are direct and easily understood, and too little to the possibilities of controlling insects by less spectacular silvicultural practices. As a result, wide-spread spraying programs are often entered into without much thought of either the ecological or economic implications.

While a general rule among forest managers in the late 1950's seemed to be "if there's a problem, spray it," a few silviculturally oriented foresters continued to try new methods such as Region 9's interplanting of aspen with white pine to protect the latter from the white pine weevil. Chemical treatments did not control the weevil and other measures were needed. Todd (1958) reported that this pest and others such as the shoot moth "... preclude the advisability of establishing new red or jack pine plantations. . . ."

As the 1950's came to a close, however, Region 9 planned a good deal of chemical control "... within the limits dictated by economic and biologic considerations. . ." (Hermel 1959). R-9 foresters expected to spray about 49,000 acres against the Saratoga spittlebug, pine sawflies, spruce budworm, and European pine shoot moth, with 50 acres each to be field tested against the white pine weevil and the Zimmerman pine moth (*Dioryctria zimmermani* (Grote)). Estimated total cost for this proposed 1960 control was $126,500.

According to available records, in 1960 actual control in the 16 Eastern national forests was much less—about 29,000 acres (fig. 2). Although it had been estimated that more than 41,000 acres would be sprayed for spruce budworm, for instance, actually just more than 24,000 acres (in the Superior) were treated. Nevertheless, the new decade started off with a bang because 1960 was the largest spray year to date. In fact, the early 1960's were the years of highest chemical control in the history of Eastern national forests. One contributing factor was the "every tree must grow to maturity" philosophy, particularly in plantations during this period. The thinking was that the time and money invested in planting each tree would be wasted if the tree did not mature. Perhaps another contributing factor was that pest control was financed from a separate fund and not by the forest or ranger district. If ranger districts had been required to budget for pest suppression, forest personnel might have thought twice about the cost of insect control if it meant cancelling their other work. Nevertheless, some foresters and entomologists resisted political and other pressures

> to treat areas with chemicals when it was clear to them that treatment would not be needed and could have undesirable side effects. For example, when questioned by the Chippewa and Superior National Forest Supervisors, [A. C. Hodson] explained to them that . . . our long-term studies showed no serious stand damage if most of northern Minnesota was not sprayed for forest tent caterpillar control.[27]

Hydraulic sprayer applying DDT to control the European pine shoot moth in the Manistee National Forest in 1957.

Forest worker spraying red pine with a backpack mistblower.

[27] *Hodson, A. C. Professor Emeritus, Department of Entomology, University of Minnesota. Letter to Richard Fowler. July 13, 1984.*

Ie suggested the most that should be done would be o treat campsites and some resort areas (a large-cale shade tree project).

Although Region 7 records for this period are in-omplete, we do have evidence that forest entomolo-ists did some control work in the first half of 1961. pest control accomplishment report to the Chief R-7 Forester 1961), for instance, shows the follow-ng forests spent a total of more than $3,100 on these pecific insects:

llegheny	white pine weevil	$1,809.73
reen Mountain	balsam woolly aphid	500.00
Ionongahela	larch sawfly	17.59
	white pine weevil	293.00
hite Mountain	balsam woolly aphid	500.00
		$3,120.32

he $1,000 spent against the balsam woolly aphid eally an adelgid) (*Adelges piceae* (Ratz.)) on the reen and White Mountain Forests was probably for iological control. In 1961 forest entomologists re-lased 10,000 adult *Laricobius erichsonii* (Rosen.) etles (imported from Germany) in these two rests and in Maine. The beetles were dispersed at different locations as colonies of 500. While early idications showed that the beetle release was suc-cssful, foresters planned that the beetles' effective-rss against the aphid would be evaluated for sev-eal years after their release to help decide future ahid suppression efforts.

During this time, the managing editor of *Organic Crdening and Farming* wrote to Region 7 express-ig concern about the possible ill-effects of mass sraying on American bird life.[28] Roy Olson, Assis-tnt Regional Forester, answered, in part, as follows:

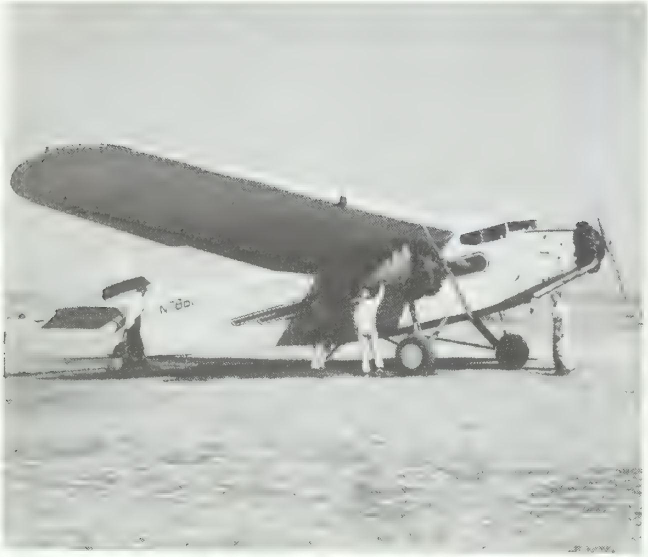
> We hold, as our primary objective, the control of forest insects and diseases by silvicultural and management practices. The use of direct control methods employing chemicals by mass application is a last resort.
>
> In the Northeast we have had very few control projects employing aerially dispersed chemicals. The areas have been small and great care is used to apply the chemicals only in the place where they are needed.[29]

[28]*Franz, Maurice. Managing Editor,* Organic Gar-deing and Farming. *Letter to S. P. Shaw, Forest Seice, Upper Darby, Pennsylvania. March 1, 1960.*
[29]*Olson, Roy W. Assistant Regional Forester. Letter to* Organic Gardening and Farming. *March 11, 1960.*

Author Wilson releasing parasites to control European pine shoot moth in the Manistee National Forest.

Ironically, 1962, the year Rachel Carson's book *Silent Spring* first appeared in hardback, was also the largest spray year in what is now the Eastern Region—DDT was being sprayed on more than 104,000 acres of the total of 109,000 acres sprayed that year (fig. 2). That year major control projects took place against the spruce budworm (56,000 acres on the Superior), jack pine budworm (37,000 acres on the Chippewa and Hiawatha), and pine tussock moth (8,700 acres on the Chequamegon).

The spruce budworm continued to receive attention in Minnesota on the Superior National Forest in 1963. In June of that year, Assistant Regional Forester St. Amant (1963) summarized a number of current reports by writing, "The Superior National Forest is treating 40,000 acres along scenic roads and in campgrounds" for the spruce budworm. Although some or all of this spraying may have taken place, we do not have records showing its completion. A table submitted to the Regional Forester by Superior's Forest Supervisor Neff (1963) showed that 1,938 pounds of DDT used on the Superior were paid for by Federal Insect and Disease Control funds in FY 1963. We calculated that at the rate of 0.5 lb/acre, more than 3,800 Superior acres were treated



A Ford Tri-Motor similar to the one used for spraying 8,735 Chequamegon National Forest acres with DDT against the pine tussock moth in 1962. This plane had a carrying capacity of 400 gallons.

with DDT for the spruce budworm that year (appendix II, p. 46).

As for another pest in Region 9, Ryan (1963) reported that the 1962 spraying on the Chippewa had reduced the jack pine budworm population by 98 percent. On the Hiawatha, Millers (1963) found the jack pine budworm "... at a low level, and with intensified elimination of open-field jack pine, chances of future outbreaks will be reduced." However, Van Denburg (1963) reported that although control efforts were needed in 1963, population levels had increased drastically in the Huron-Manistee National Forests late in the year and said that tentative plans for 1964 called for large spray programs against the budworm.

The pine tussock moth, which had achieved attention on the Chequamegon in 1962 (8,735 acres were sprayed with DDT), had declined greatly by spring of the next year (St. Amant 1963). During this same period, the Hiawatha had a severe pine tortoise scale infestation. After watching dominant and other jack pines die and noting that salvage control in 1963 had failed to halt the problem, foresters managed this situation by cutting and burning several "40's." Private landowners in the area of the Hiawatha did nothing about the infestation, and, contrary to what might have been expected, their trees survived and even grew to saw-log size.

Although Region 7 annual reports for the early 1960's are not available, in Region 9 a new wave of conservative use of insecticides became evident in 1964—no doubt in part as a reaction to *Silent Spring*. This cautious attitude was apparent in a letter written in April by R-9's Regional Forester George S. James. He listed the 1964 insect control projects approved by the Federal Pest Control Review Board against the spruce budworm on the Superior (DDT on 2,600 acres); the Saratoga spittlebug on the Chequamegon, Nicolet, and Manistee (DDT on 210, 890, and 200 acres, respectively); and the jack pine budworm on the Huron-Manistee (malathion and dimethoate as needed) and then noted:

> Special precautions (buffer strips) are to be observed along streams and other sensitive areas. The jack pine budworm infestation on the Huron National Forest, Michigan, involves the nesting habitat of the Kirtland's Warbler. No spraying will be done ... within two miles of any known nesting sites.... Malathion will be applied by helicopter....
>
> A number of new insecticides are being field tested on the Huron-Manistee N. F.'s. Dimethoate (Cygon), Malathion, Sevin, and Guthion are scheduled this spring....
>
> Your help in providing any pesticide evaluation techniques, especially involving the fisheries resource, would be appreciated.[30]

A July report from Acting Assistant Regional Forester Moore (1964) showed a reversal of thinking about spraying against the spruce budworm, "The 4,000 acres proposed for control on the Superior were not sprayed as a result of a reassessment of involved recreational values." Available records show no control against the Saratoga spittlebug on the Chequamegon, Nicolet, or Manistee in 1964. Similarly against the jack pine budworm, Moore (1964)

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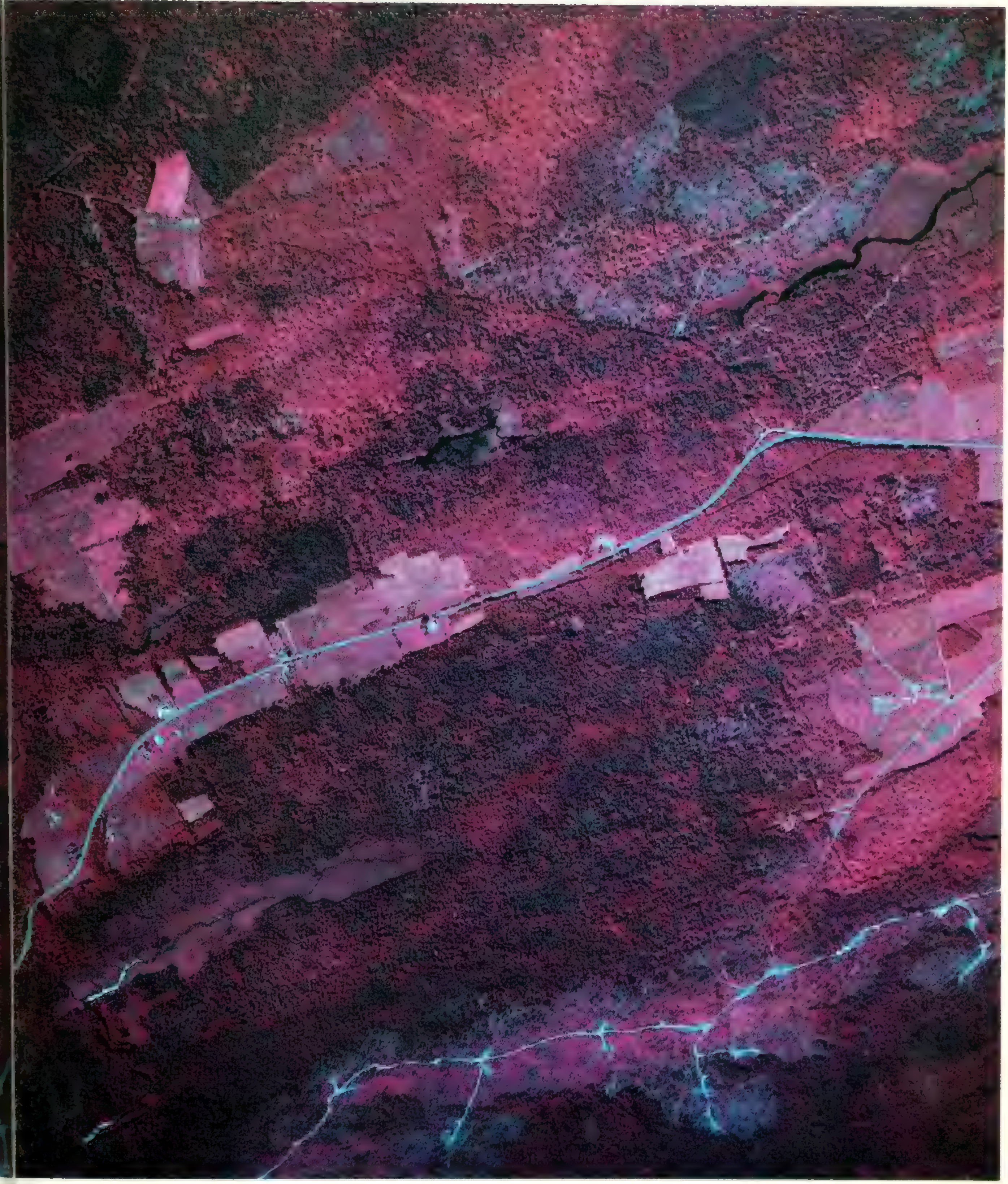
[30]*James, George S. Regional Forester, R-9. Letter to Robert W. Burwell, Regional Director, Bureau of Sport, Fisheries and Wildlife. April 28, 1964.*



nfra-red photograph of spruce budworm defoliation. The bright red indicates hardwoods and the maroon indicates fir and spruce. Gray indicates tree mortality.

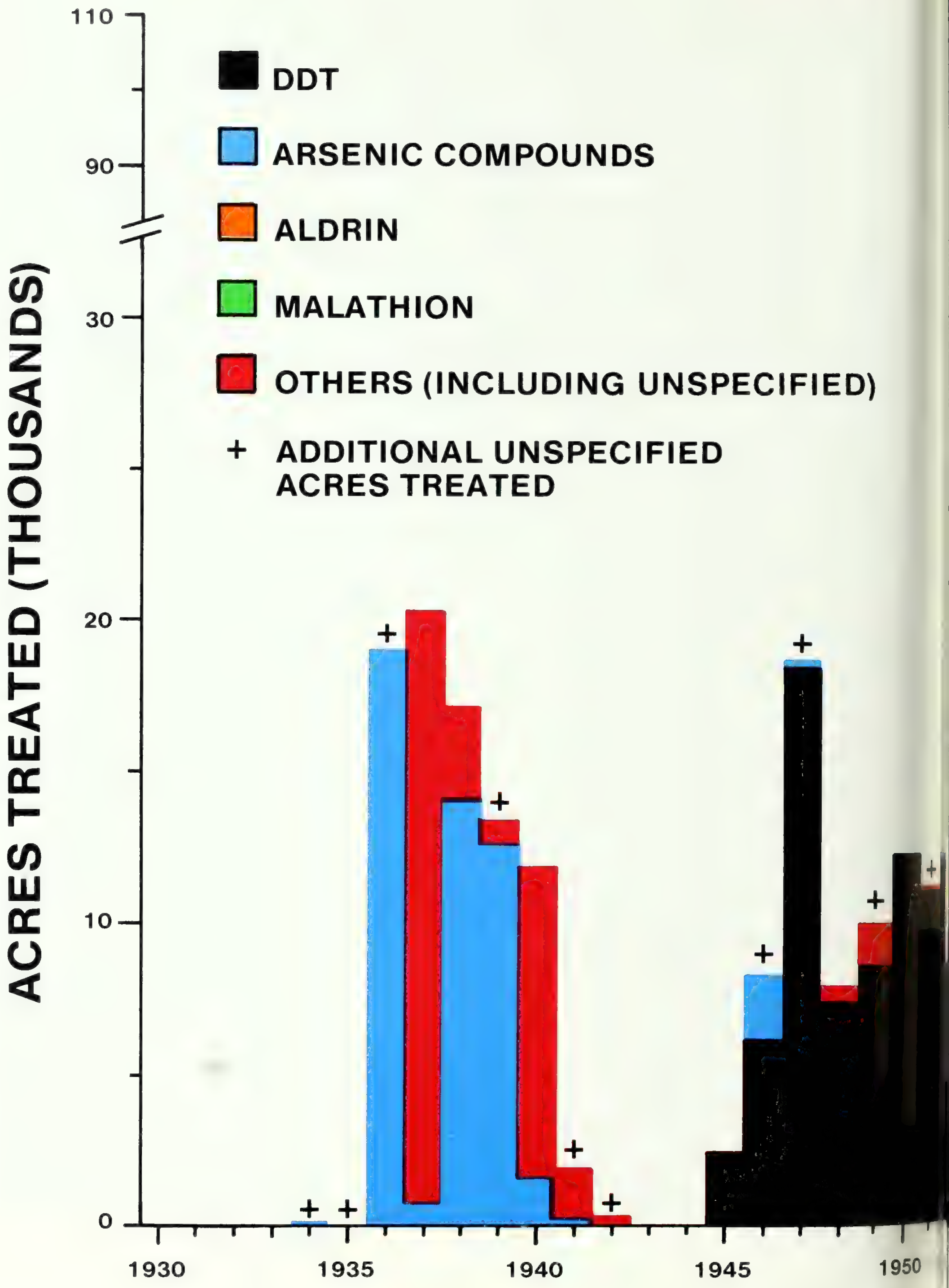
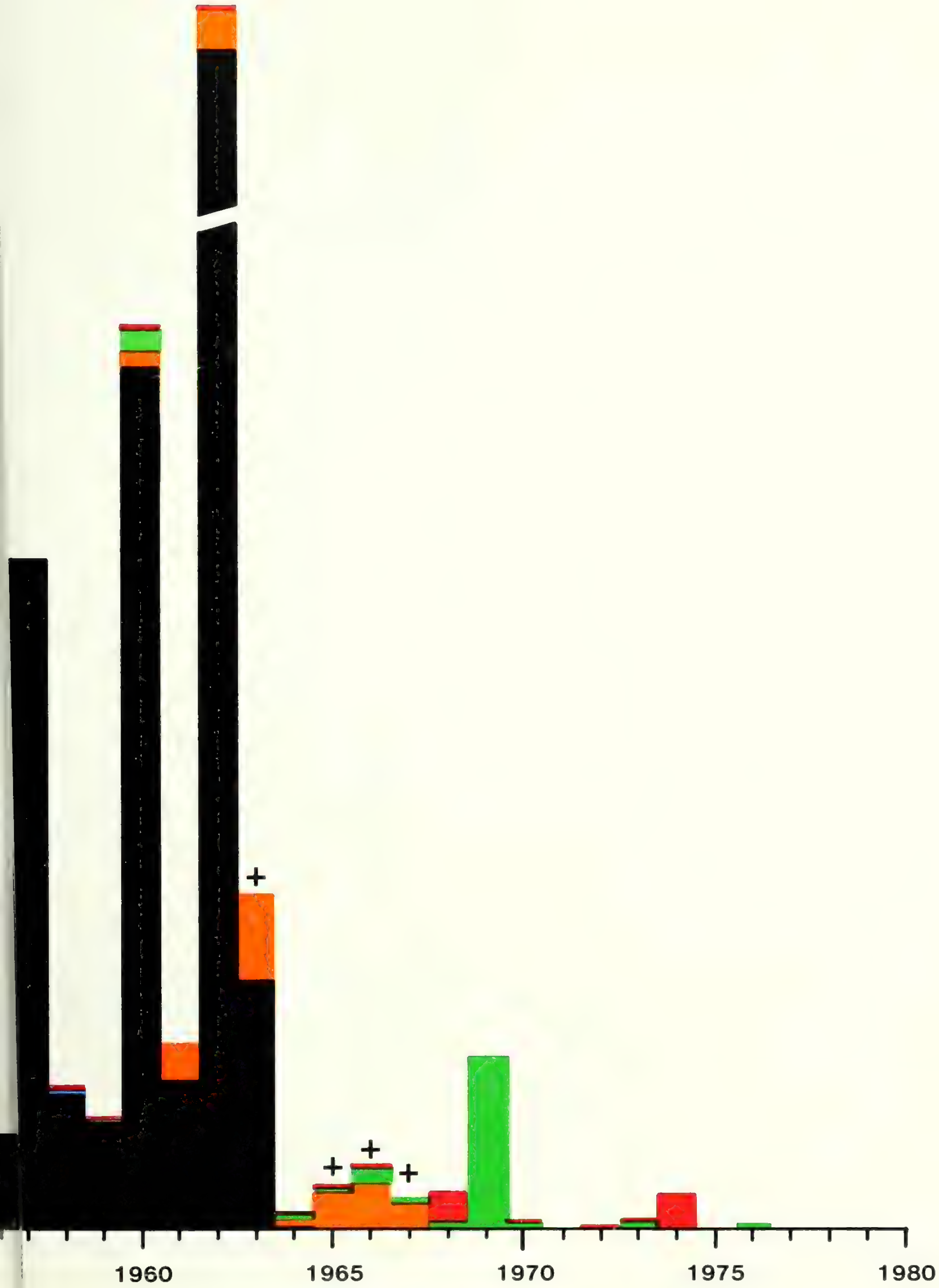


Figure 2.—*Acreages of Eastern Region national forest land treated with insecticides by years, 1930-1980.*


+
+
+
+
1960
1965
1970
1975
1980

wrote, "The anticipated control project on the Huron-Manistee did not materialize."[31]

Final figures for 1964 showed that in the Region's 16 national forests about 500 pounds of chemicals were sprayed. Of these, only 64 pounds were DDT, which was used (experimentally) against the jack pine budworm and the Saratoga spittlebug (60 acres on the Manistee and 4 acres on the Huron, respectively, appendix II, p. 50 and p. 44). These two tests (Batzer and Millers 1965, Millers and Wilson 1965) concluded the use of DDT in the Eastern national forests. Eichers *et al*. (1968) found that during 1964 farmers in 19 of the 20 Eastern Region States (records for West Virginia were unobtainable) used more than 25 million pounds of various insecticides to control crop and livestock pests, including more than 2.1 million pounds of DDT. They also reported that "... total insecticide production has increased an average of about 5 percent a year in the last 4 years." A State and Private Forestry (S&PF) report late in 1964 showed that foresters continued to have plans for future spraying: "The Huron-Manistee National Forest has proposed 62,000 acres for possible control [of the jack pine budworm] in 1965" (S&PF 1964). But DDT was almost totally out of favor with foresters, and DDT substitutes such as malathion were to be field tested at this point.

Thus the golden, yet well-tarnished, age of DDT ended in what is now the Eastern Region. Long-time proponents of silvicultural control and timber sale activities were once again listened to, and the foresters and entomologists of the Eastern Region Forests were developing an integrated pest management future.

[31]*In a January 8, 1965, letter to Les Line, Secretary of the Michigan Audubon Society, Acting Forest Supervisor D. D. Westerburg explained why the control project was cancelled:*

> *The pilot control test proposal was turned down because of insufficient funds available at the Washington Office. Recent fires and windstorms have produced extensive bark beetle outbreaks on the Western Forests. Bark beetle control is considered more important than suppression of defoliators, and consequently, no funds remained for the jack pine budworm pilot test.*

The Post-DDT Era

(1965-1980)

The final 15 years of this study—the post-DDT era—demonstrate an overall emphasis on the economic and ecological aspects of control; foresters began to work towards intensive forest management including integrated pest management (IPM). In this history, IPM is defined as a forest management system that considers all possible pest control techniques and methods (e.g., cultural, chemical, biological, legal, mechanical) to keep insect populations below economically injurious levels.

The concept of IPM was not embraced immediately when the use of DDT was phased out. As Newsom (1980) states, "The basic principles of biology and ecology were largely forgotten or ignored" during what he calls the "Dark Ages" of integrated pest control (the late 1940's through the mid-1960's) when "... pest management consultants [functioned] essentially as 'pesticide peddlers.'" It would take time for attitudes and procedures to change in order to bring back and improve upon early IPM systems such as one that Dwight Isely developed against the boll weevil (*Anthonomus grandis grandis* Boheman) in the south in the 1920's.

Blair and Edwards (1980) found that

> Major problems from the late 20's until late 60's that hindered the growth of IPM were: (1) no widespread environmental concerns, (2) lack of insecticide resistance problems, (3) inexpensive and readily available insecticides, and (4) lack of adequate money for IPM program development and personnel in both research and extension.

No doubt the issuance of the 1965 report "Restoring the Quality of Our Environment" by President Lyndon B. Johnson's Science Advisory Committee helped confirm the USDA Forest Service's

> ... policy of not using persistent pesticides in action programs to control forest insects in all cases where research and field tests have demonstrated that a commercially available non-persistent chemical or non-chemical methods will accomplish a control job effectively and safely (USDA Forest Service 1966).

The foreword to the report *Forest Insect Conditions in the United States 1965* gave a stringent admonition:

> The Forest Service also warns that pesticides if improperly used can be injurious to humans, fish, and wildlife; that the directions and precautions governing their use should be closely followed; and that overdosing is dangerous and should be avoided. Special care should be taken in applying pesticides along the edges of rivers and streams, around ponds and lakes, and in grazing and foraging areas (USDA Forest Service 1966).

The National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. 4321, 4331-4335, 4341-4347) definitely made a large impact on forest insect control in the post-DDT era:

> The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality (USDA 1978).

A main provision of this Act was the requirement of an environmental impact statement to be included "in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment" (USDA 1978).

A second major act during this era was the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended in 1972. Under this Act, the Environmental Protection Agency required the certification of applicators and the registration of all chemicals (USDA 1983).

As part of the growing concern about the environment, forest entomologists in the mid-1960's began experimenting with chemicals that were far less toxic than DDT, had a lower residual life, and usually could be applied in smaller dosages. For example, Wilson and Millers (1966) tested the application of malathion with a helicopter in 1965 and found that low-volume malathion (10 fluid ounces per acre) reduced a spittlebug population by more than 99 percent. Van Denburg (1965) reported that the low-volume malathion might "... revolutionize spittlebug control in the Lake States." While various proposals for 1965 called for chemical control of pests on more than 60,000 acres, available records show that about 1,500 acres were actually treated (Fowler 1973a, 1973b).

Concern about DDT remained strong the next year in the Forest Service. For instance, in August 1966 District Rangers on the Ottawa received a memorandum stating, "We can no longer use DDT for control. A solution of lead arsenate in water is being recommended for use as a control measure" against the redheaded pine sawfly.[32] Also, later that year a Lake States report referred to "the continuing search for a replacement for DDT" (USDA 1966). Foresters did spray more than 2,000 pounds of four other insecticides during 1966—aldrin, malathion, lindane, and carbaryl (appendix II). At the time, Eastern Region farmers reduced their use of DDT from more than 2.1 million pounds in 1964 to about 1.5 million pounds in 1966 (28 percent reduction), but overall use of insecticides by farmers was up from more than 25 million pounds to nearly 35 million (39 percent increase) (Eichers *et al*. 1968, Eichers *et al*. 1970).

In 1967, the Forest Service as a whole continued its "... efforts to use safer, more effective control methods for economically important forest insects." They placed greater emphasis on biological control techniques and "... continued to screen and test nonpersistent pesticides for use in suppressing forest defoliators" (Pierce 1968).

The Forest Service in 1968 again stressed control techniques that relied less on the use of chemicals—particularly biological and cultural controls. Pilot studies on non-persistent pesticides continued to be conducted during that year. According to Robert G. Doerner (1968), who compiled the Region's annual report, defoliators were again the worst pests in the Eastern States—"Of the 22 forest pest problems encountered, 14 were related to defoliators."

Although the Forest Service sprayed a larger amount of insecticide in 1969 than it had for 5 years, it used only malathion. That chemical was sprayed on more than 5,500 acres (fig. 2), in particular,

[32]*Kickbusch, William L. Timber Management Staff Assistant. Memorandum to District Rangers. August 11, 1966.*

Forest technician injecting aldrin into the soil with a wand for white grub control in a Hiawatha National Forest red pine plantation in 1967.

against the Saratoga spittlebug on the Chequamegon, Hiawatha, and Huron (appendix II, p. 44).

That was the last year that chemicals in very large amounts were used in the Eastern Region national forests. In March of 1970, a number of suppression programs were planned in the Lake States, including a 373-acre project on the Chequamegon against the Saratoga spittlebug.[33] Existing records show that only 61 acres (fig. 2) actually were sprayed. Chemicals were used against the gypsy moth in the White Mountain (carbaryl on 15 acres) and against the redheaded pine sawfly in the Manistee and Ottawa (malathion on 45 acres and 1 acre, respectively) (Fowler 1973a, 1973b).

The next year no insecticides were used in Eastern Region national forests, and in 1972 only 12 acres were sprayed—carbaryl was used on the White Mountain against the gypsy moth (appendix II, p. 53). The only spraying on Eastern Region national forests in 1973 was experimental on 120 acres—four chemicals were tested against the redhumped oak-

[33]*Hastings, A. R. Entomology Section Head, St. Paul Field Office, S&PF. Letter to Dr. James B. Eller, U.S. Fish and Wildlife, Pesticide Monitoring. March 19, 1970.*

Silvicultural controls such as snow-depth-pruning were used on this stand of red pine to control the European pine shoot moth in 1969. Note that the branch tips on the unpruned tree on the right are below the snow line—shoot moth larvae hibernating in these branches are insulated from the cold.

worm (Fowler 1973b). Carbaryl was found to be the most effective in reducing the larval population of this pest.

Similarly in 1974, carbaryl was used experimentally against the cherry scallopshell moth on 225 Allegheny acres—this treatment marked the first time this insect was sprayed in Eastern forests. That same year carbaryl was also used against the gypsy moth on 800 Manistee acres (appendix II, p. 53).

No insecticides were used in the national forests of the Region in 1975, and only one was used in 1976—

This stand of red pines has received early-basal-pruning, and duff beneath these trees has been scraped away to protect them from the pine root collar weevil. Because there is no longer shade at the bases of the trees, the weevils can't live in this environment nor lay their eggs.

Bell 47 helicopter being made ready for liftoff; it is equipped with two Beecomist 350 rotary spray nozzles with 100-micron sleeves.

40 pounds of malathion against the Saratoga spittlebug on the Nicolet (appendix II, p. 46). During the same year, farmers in Region 9 used more than 23.5 million pounds of insecticide on major field crops, hay, and pasture and rangeland, down 6 percent from 1964 usage and 33 percent from 1966 (Eichers *et al*. 1978).

No chemicals were used in the Eastern Region's forests during the final 4 years of this 50-year study. The long shadow of *Silent Spring* apparently had projected deeply into the 1970's and eclipsed the attitudes of the 1950's and early 1960's. Rachel Carson's facts and forecasts had finally made their total impact.

Historically, human thought about a variety of matters has swung far in one direction, come to center, and then swung equally far in the opposite direction. This kind of pendulum swing seems to have happened to national forest pest managers who were extremely spray conscious during the DDT era, but who became concerned about the environment late in the 1970's and drastically limited spraying. *Silent Spring* helped put the philosophy of integrated pest management (IPM) onto the horizon in the early 1960's, and to the zenith by the late 1960's. In IPM, alternate control methods were considered first and "no control" was as valid a pest management recommendation as was spraying. Managers strived for IPM, but seldom, if ever, realized it because of the lack of appropriate technology as well as the presence of constraints involving environmental concerns. When forest managers had to make judgments based on whether it was economically justifiable to use biological, chemical, and silvicultural controls, programs were curtailed and "no control" was the prevalent choice.

In retrospect, one asks whether the forest managers had gone too far, like the pendulum, by not applying more chemical control in the 1970's. The reduced spraying has caused some losses. For instance, Kucera (1985) states:

> Large, outbreak-sized populations generally develop in extensive and continuous areas of mature and overmature balsam fir—the preferred host of the spruce budworm. . . .
>
> By the mid-1970's, more than 60 percent of the eastern spruce-fir forests had reached the mature or overmature stage, and this large area of susceptible hosts provided a huge source of the budworm's preferred foods: buds, male flowers, and foliage from mature or overmature trees. The outbreak, which began in the mid-1970's, peaked in 1978.
>
> . . . .
>
> In the Lake States, losses attributed to the latest outbreak began around 1980. From 1977 through 1982, approximately 485,000 cords (1.2 million m^3) were killed by the budworm. . . . These cords represent almost one-half of the spruce-fir type. The remainder of the stands are again being defoliated after a 1- to 2-year decline.

Additionally, vast acreages of jack pine in the Lake States have been killed by the jack pine budworm and deformed by the white pine weevil. Numerous red pine plantations throughout the Northeast have also been attacked by the Saratoga spittlebug, and losses there have been considerable. Other pests have also caused large losses. Because spray programs on State-owned land in many parts of the Region have not abated, we must wait for the future to decide which strategy has been the most beneficial.

As we come to the end of the first 50 years of insect suppression in the Eastern Region national forests—which incidentally is also the end of the first 75 years of the USDA Forest Service—we realize we must continue to look to the past in order to help predict the future.

The Next 50 Years . . .

(1981-2030)

We cannot resist making some predictions based on the past as we look forward to the year 2030, when the Forest Service will be 125 years old and the history of forest insect suppression will have reached its centenary.

Our first prediction is that forest managers will continue to use integrated pest management techniques to solve pest problems. Most managers realize that they must include pest management when they plan stand management and not depend upon expensive control procedures after various crises arise. Furthermore, the philosophy held by some forest managers that all trees must live and all harmful bugs must die will continue to change. Environmental concerns and economics will continue to be partly responsible for this change in philosophy. Insecticides will not be a thing of the past. New chemicals will be developed and used, but their use will be more carefully planned biologically, environmentally, and economically. New knowledge about (1) the pests themselves, (2) the fate of chemical insecticides in the environment, (3) herbicides needed to control overstory and understory, and (4) substitutes for chemicals will continue to shape pest prevention and suppression in the future. However, insecticide use will continue to be a vital component of integrated pest management.

The future will continue to hinge on the past. Because large acreages of single species or mixtures of closely related tree species (especially in the Lake States) were planted in the 1930's, these must be closely monitored. Although these plantations have grown beyond danger from pests such as white grubs, the Saratoga spittlebug, and the redheaded pine sawfly, they are at the age when other pests such as budworms and bark beetles will attack them. Forest managers must prepare to meet this event.

In the future, more trees will be grown under intensive culture management. Agroecosystems of hybrid *Populus* and other species could set the stage for extremely damaging insect outbreaks, and the problems may be worse than those of pine plantations in the past. Selected species or clones with limited genetic variability also may be particularly vulnerable to injury. However, intensive culture systems will be advantageous because they can allow manipulation of treatment to prevent or control pests in ways not available to natural forests or mature stands.

Sometime during the next 50 years, the gypsy moth will occupy all available ecological niches coast-to-coast, including valuable hardwood stands in Eastern Region national forests. The gypsy moth is not the only exotic pest that will affect the forests. The introduction of other new pests is inevitable and eradication will be impossible. The costs of eradicating pests—in terms of environmental damage, adverse public opinion, and actual dollars—will be prohibitive.

We believe that pest problems will be reduced overall as stands and whole forests are brought under intensive management. But this state of management is a long way into the future. The low budgets of the 1980's for national forest management and research will no doubt extend the time necessary to achieve intensive management. Although insects are one of nature's ways of harvesting overmature or overcrowded stands and making way for younger, more vigorous stands, insect harvests will continue to be as wasteful as they have been spectacular.

Finally, we predict that management will rely more on the computer, and programs will be planned through systems science approaches. Insects will be monitored by satellites; and, perhaps, pest control with lasers, genetic engineering of insect pathogens and other still-to-be-developed tools too unusual to predict will be only the beginning of future insect management. Here ends our prognostication.

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APPENDIX I: ACQUISITION AND ADMINISTRATION OF EASTERN REGION NATIONAL FORESTS

Those readers who wish to trace further the various kinds of projects that have taken place in Eastern Region national forests should be aware of the regional name and boundary changes as well as forest name changes and consolidations. Such an awareness will help researchers in contacting the appropriate Federal Regional Record Centers as well as in searching the National Archives.

The Forest Service Regions, called Districts until 1930, were initially administered by Regional (District) Foresters stationed in Washington, DC. In 1908, the Regional Foresters were transferred to field headquarters—except for the R-7 Regional Forester, who remained in Washington. He was transferred to the field in 1934.

The three Lake States—Minnesota, Wisconsin, and Michigan—were part of the Rocky Mountain Region (R-2), headquartered in Denver, CO, from 1908 to the end of 1928—except for a brief period from March 1909 to February 1913. During this latter period, the Lake States were part of the Northern Region (R-1), headquartered in Missoula, MT. The remaining northeastern States were part of what was then the Eastern Region (R-7).

Region 9 was formed on December 22, 1928, and was called the Lake States Region until 1932 (fig. 3). The States of Indiana, Illinois, Iowa, Missouri, and Ohio were transferred from Region 7 to Region 9 in 1930. In 1932, Region 9's name was changed to North Central Region (fig. 4). The final change occurred on March 1, 1966, when Region 7 was abolished and the States from Maine to Maryland and Ohio were added to Region 9 (table 4). Also, Region 9 was given the former name of Region 7—the Eastern Region. The State of North Dakota was part of Region 9 from January 3, 1930, until the 1966 changes took place. (After 1917 when the Dakota National Forest was abolished, the State did not contain any National Forests.)

Figure 3.—*National forests of the Northeastern States, 1928-1932. Region 9 is the Lake States Region and Region 7 is the Eastern Region.*

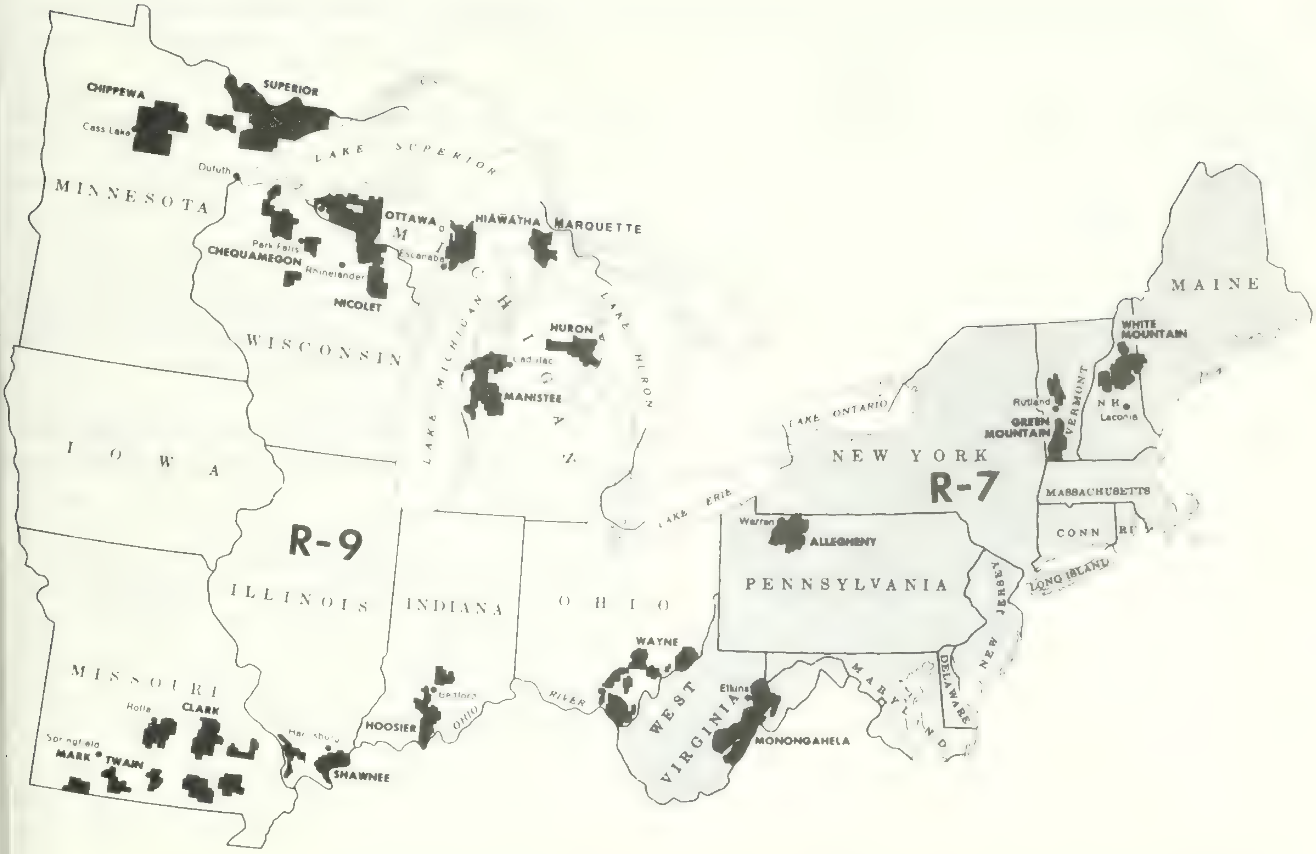

Figure 4.—*National forests of the Northeastern States, 1932-1966. Region 9 is the North Central Region and Region 7 is the Eastern Region.*

Table 4.—*Eastern Region National Forest acquisition dates, name changes, and consolidations*

National forest	Year acquired[a]	Notes
LAKE STATES		
Chequamegon	1928	
Chippewa	1902	Called Minnesota NF until June 22, 1928.
Hiawatha (Marquette 1909)	1928	East Unit: Established as Marquette NF on February 10, 1909; made part of Michigan NF in 1915; name changed back to Marquette NF in 1928. The Marquette was abolished February 9, 1962, and made part of the Hiawatha NF. West Unit: Established in 1928. Around 1935, the Hiawatha and Marquette were combined administratively and were referred to as Upper Michigan National Forests until 1962.
Huron	1909	Established as Michigan NF; name changed to Huron NF in 1928. On May 10, 1945, the Huron was consolidated administratively with the Manistee; they were called Lower Michigan National Forests. In 1962, the name was changed to Huron-Manistee National Forests.
Manistee	1933	(See notes about consolidation under Huron NF.)
Nicolet	1928	
Ottawa	1928	
Superior	1902	
MIDLANDS		
Hoosier	1933	(See notes under Wayne NF.)
Mark Twain (Clark 1933)	1935	In September 1953, the Clark and Mark Twain were combined administratively and called the Missouri National Ranger Districts were transferred to the Shawnee.) In 1962, the forests again divided into the Clark and Mark Twain and the Ranger Districts were returned. On June 30, 1973, the name "Clark" was abolished and the forest was made part of Mark Twain NF.
Shawnee	1933	(See Ranger District transfers under Mark Twain.)
NORTHERN APPALACHIA		
Allegheny	1920	
Monongahela	1915	
Wayne	1934	On August 20, 1949, the Wayne combined administratively with the Hoosier NF; they were called Wayne-Hoosier Purchase Units. In 1951 each unit was proclaimed a national forest but they remained combined.
NEW ENGLAND		
Green Mountain	1928	
White Mountain	1914	

[a]Year given is earliest date of the forest (e.g., when obtained from public domain land, as forest reserves (1902), by purchase or transfer, etc.).

APPENDIX II: SUPPRESSION OF TARGET INSECTS

This appendix delineates (in descending order of total regional acres treated) the insects receiving specific insecticide treatment by subregion, national forest, year, and the results obtained. "Year treated" refers to calendar year (CY) throughout this report; when information was taken from fiscal year (FY) reports, it was placed with (CY) information. Dashes (—) in various columns indicate that no data were available or that records were incomplete. Under "acres treated," "0+" indicates that we have a document reporting that treatment occurred, but the document gives no data on exact acreage. E-coded numbers indicate treatment was experimental. Under "Results," percentages and quoted descriptions (e.g., 90 percent, "satisfactory") were taken directly from available documents. (For the most part, these are not scientific judgments, and we had no guidelines to help us determine their consistency.) Unquoted descriptions are inferences made by the authors when reports were not specific.

Insecticides have been applied by a variety of means. The "Application method" classifications in Appendix II are defined as follows:

- Aircraft — insecticide is applied as a liquid; this classification includes both fixed-wing airplanes and helicopters.
- Mistblower — insecticide is injected into a fast-moving large-volume air flow; this classification includes both vehicle-mounted and back-pack equipment.
- Hydraulic sprayer — insecticide is carried in a large volume of liquid; this sprayer is mounted on or pulled by a vehicle.
- Hand sprayer — back-pack, knapsack, or similar hydraulic sprayer carried by a person; this classification includes a modified back-pack sprayer fitted with a wand for inserting insecticide into soil.
- Planting machine — insecticide is dispersed into furrows during tree planting; the insecticide dispersal equipment is attached to the tree planting machine.
- Dipped stock — tree roots (planting stock) are dipped into an insecticide before planting.
- Broadcast on ground — insecticide, e.g., bait, is spread on the ground surface manually or by machine.

SARATOGA SPITTLEBUG

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			LAKE STATES			
Chequamegon	1949	DDT	--	Mistblower	55	90
	1951	DDT	1	Aircraft	70	95
	1951	DDT	0.5	Mistblower	80	95
	1952	DDT	1	Aircraft	618	95
	1952	DDT	--	Mistblower	200	95
	1953	DDT	1	Aircraft	1,921	90
	1954	DDT	1	Aircraft	3,459	86-100
	1955	DDT	1	Aircraft	2,195	"good"
	1956	DDT	1	Aircraft	773	"satisfactory"
	1957	DDT	1	Aircraft	544	"satisfactory"
	1958	DDT	1	Aircraft	755	"satisfactory"
	1959	DDT	1	Aircraft	575	--
	1961	DDT	1	Aircraft	43	--

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(Table Continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
	1962	DDT	1	Aircraft	155	90
	1963	DDT	1	Aircraft	165	—
	1968	Malathion	0.75	Aircraft	3	—
	1969	Malathion	0.75	Aircraft	528	96-100
					Total 12,139	
Hiawatha	1948	DDT	1	Aircraft	480	98-99
	1949	DDT	—	Mistblower	300	—
	1950	DDT	1	Aircraft	407	90
	1953	DDT	1	Aircraft	1,028	98
	1954	DDT	1	Aircraft	575	99-100
	1955	DDT	1	Aircraft	357	"good control"
	1957	DDT	1	Aircraft	633	"satisfactory"
	1958	DDT	1	Aircraft	66	100
	1959	DDT	1	Aircraft	324	"satisfactory control"
	1960	DDT	1	Aircraft	706	"adequately controlled"
	1969	Malathion	0.60	Aircraft	90	—
					Total 4,966	
Huron	1961	DDT	1	Aircraft	192	—
	1962	DDT	1	Aircraft	680	90-99+
	1963	DDT	1	Aircraft	4,253	averaged 89
	1964	DDT	1	Mistblower	4-E	99+
	1964	Malathion	1	Mistblower	4-E	99+
	1964	Malathion	0.5	Mistblower	4-E	99
	1965	Malathion	1	Aircraft	50-E	99+
	1965	Malathion	0.5	Aircraft	50-E	25
	1965	Malathion	0.75	Aircraft	35-E	99+
	1966	Malathion	0.6	Aircraft	400	averaged 93
	1969	Malathion	0.75	Aircraft	4,908	83-100
					Total 10,580	
Manistee	1946	DDT	1 & 2	Aircraft	710-E	95
	1948	DDT	1	Aircraft	80	95
	1949	DDT	0.6	Mistblower	64-E	62-94
	1949	DDT	0.5	Mistblower	30-E	80-90
	1950	DDT	0.75	Mistblower	124	95
	1950	DDT	—	—	195	—
	1951	DDT	—	Mistblower and hand sprayer	310	—
	1952	DDT	—	Mistblower	215	95
	1959	DDT	1	Aircraft	134	"satisfactory control"
					Total 1,862	
Nicolet	1945	DDT	0.25	Aircraft	66-E	0
	1945	DDT	0.5	Aircraft	80-E	31
	1945	DDT	1	Aircraft	313-E	36
	1945	DDT	2	Aircraft	10-E	61

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(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
	1945	DDT	5	Aircraft	9-E	96-100
	1946	DDT	0.5	Aircraft	118-E	85-90
	1946	DDT	0.92	Aircraft	367-E	85-90
	1946	DDT	1	Aircraft	458-E	85-90
	1946	DDT	2	Aircraft	657-E	85-90
	1947	DDT	1	Aircraft	200-E	excellent
	1947	DDT	2	Aircraft	100-E	excellent
	1947	DDT	1	Aircraft	2,450	averaged 90
	1948	DDT	1	Aircraft	794[a]	"good control"
	1949	DDT	1	Aircraft	1,522[a]	90-100 (spit.), 80 (sawfly)
	1949	DDT	1	Hand sprayer	88[a]	95+-100
	1950	DDT	1	Aircraft	9,250	95
	1951	DDT	1	Aircraft	4,294	71-94
	1952	DDT	1	Aircraft	1,743	87-100
	1953	DDT	1	Aircraft	6,014	44-82
	1954	DDT	1	Aircraft	2,850	37-85
	1955	DDT	1	Aircraft	5,538	"excellent or satisfactory on 10 out of 13 areas"
	1956	DDT	1	Aircraft	2,098	"satisfactory"
	1957	DDT	1	Aircraft	4,710	"satisfactory on all but two plantations"
	1958	DDT	1	Aircraft	3,194	"satisfactory overall"
	1959	DDT	1	Aircraft	1,602	"satisfactory control"
	1960	DDT	1	Aircraft	1,958	—
	1961	DDT	1	Aircraft	2,154	—
	1962	DDT	1	Aircraft	1,564	99+
	1962	DDT	0.5	Aircraft	160	40
	1962	DDT	1	Hand sprayer	30	—
	1965	Malathion	0.13	Mistblower	4-E	unsatisfactory
	1965	Malathion	0.25	Mistblower	4-E	satisfactory
	1965	Malathion	0.5	Mistblower	4-E	satisfactory
	1967	Malathion	0.5	Aircraft	149	—
	1968	Malathion	0.5	Mistblower	12	—
	1976	Malathion	0.75	Aircraft	40	99
				Total	54,604	
O wa	1945	DDT	—	—	65	—
	1946	DDT	1 & 2	Aircraft	220-E	80-90
	1947	DDT	1	Aircraft	1,320	98
	1949	DDT	1	Aircraft	2,250	95-98
	1950	DDT	1.05	Aircraft	440	80
	1950	DDT	2	Hand sprayer	5-E	—
	1951	DDT	1	Aircraft	1,200	80
	1952	DDT	1	Aircraft	1,120	75
	1953	DDT	1	Aircraft	2,168	85
	1954	DDT	1	Aircraft	1,227	69-100
	1954	DDT	—	Hand sprayer	13	69-100

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(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
	1955	DDT	1	Aircraft	1,570	"good to excellent"
	1956	DDT	1	Aircraft	212	"satisfactory"
	1961	DDT	1	Aircraft	55	--
	1962	DDT	0.96	—	30	--
	1968	Malathion	0.5	Aircraft	120	"satisfactory"
				Total	12,015	
				Regional total	96,166	

[a]Treated for Saratoga spittlebug and redheaded pine sawfly simultaneously were: 251 of the 794 acres, 449 of the 1,522 acres, and 25 of the 88 acres.

SPRUCE BUDWORM

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			LAKE STATES			
Superior	1957	DDT	1	Aircraft	90-E	--
	1958	DDT	1	Aircraft	140-E	"satisfactory"
	1959	DDT	1	Aircraft	140-E	"successful"
	1960	DDT	1	Aircraft	23,990	"very good"
	1960	DDT	0.5	Aircraft	354	"very good"
	1962	DDT	1	Aircraft	54,660	97
	1962	DDT	0.5	Aircraft	1,606	97
	1963	DDT	0.5	Aircraft	3,835	"excellent"
				Regional total	84,815	

REDHEADED PINE SAWFLY

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
Chequamegon	1935	Lead arsenate	—	—	0+	--
	1946	DDT	—	Hand sprayer	300	90-95
	1947	DDT	1	Aircraft	1,025	30-100
	1947	DDT	0.5	Aircraft	1,025	0-50
	1947	DDT	0.25	Hand sprayer	1,593	90-98
	1948	DDT	0.09	Hand sprayer	1,685	90
	1949	DDT	0.17	Hand sprayer	2,533	90
	1949	DDT	0.19	Hand sprayer	425	90
	1949	DDT	0.21	Hand sprayer	700	90
	1949	DDT	0.25	Hand sprayer	50	90
	1950	DDT	—	Mistblower	35	90
	1950	DDT	—	Hand sprayer	748	90
	1951	DDT	—	Hand sprayer	110	95
	1960	DDT	—	Hand sprayer	40	successful
				Total	10,269+	

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(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
Chippewa	1939	Lead arsenate	—	Hand sprayer	11	--
	1948	DDT	—	Hand sprayer	93	90
	1949	DDT	—	Hand sprayer	95	"good"
	1953	DDT	—	Hand sprayer	50	80
					Total 249	
Hiawatha	1936	Lead arsenate	—	Hand sprayer	454	"effective"
	1938	Lead arsenate	0.03	Hand sprayer	2,260	satisfactory
	1938	Lead arsenat	—	Hand sprayer	1,587	--
	1939	Lead arsenate	0.71	Hand sprayer	1,388	--
	1940	Lead arsenate	0.05	Hand sprayer	1,404	--
	1945	DDT	—	Hand sprayer	1,935	--
	1946	Lead arsenate	—	Hand sprayer	2,125	"satisfactory"
	1946	DDT	—	Hand sprayer	640	90-95
	1947	DDT	—	Hand sprayer	1,233	80-95
	1948	DDT	1	Hand sprayer	965	60-99
	1957	DDT	—	Hand sprayer	236	100
	1958	DDT	1	Aircraft	54	100
	1959	DDT	—	Hand sprayer	47	--
	1960	DDT	1	Aircraft	88	successful
	1960	DDT	—	Hand sprayer	10	--
	1969	Malathion	1	Hand sprayer	3	100
					Total 14,429	
uron	1935	Lead arsenate	—	Hand sprayer	0+	"not very satisfactory"
					Total 0+	
anistee	1934	Lead arsenate	—	—	0+	--
	1935	Lead arsenate	—	—	0+	--
	1936	Lead arsenate	—	Hydraulic sprayer	0+	"very effective"
	1938	Lead arsenate	—	—	10,048	satisfactory
	1939	Lead arsenate	—	—	10,636[a]	--
	1939	Lead arsenate and Nicotine sulphate	—	—	300[b]	--
	1939	Nicotine sulphate	—	—	680[b]	--
	1940	Lead arsenate	—	Hydraulic sprayer	177	--
	1946	DDT	1.7	Aircraft	1,800-E	"satisfactory"
	1946	DDT	—	Hand sprayer	800-E	99
	1947	DDT	1	Aircraft	3,224	30-99
	1947	DDT	—	Mistblower	0+-E	"effective"
	1947	DDT	—	Hand sprayer	25	--
	1948	DDT	1	Aircraft	2,240	80-90
	1948	DDT	—	Hand sprayer	300	80
	1951	DDT	—	Hand sprayer	12	95
	1958	DDT	—	Hand sprayer	30	"satisfactory"
	1960	Malathion	2	Aircraft	202	--
	1969	Malathion	1	Hydraulic sprayer	50-E	99
	1970	Malathion	0.75	Aircraft	45-E	100
					Total 30,569+	

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(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
Nicolet	1947	Lead arsenate	--	Hand sprayer	87	"heavy kill"
	1947	DDT	--	—	0+	--
	1948	DDT	1	Aircraft	549[c]	80-99
	1948	DDT	1	Hand sprayer	452	95-99+
	1949	DDT	1	Aircraft	449[c]	80 (sawfly), 90-100 (spit.)
	1949	DDT	1	Hand sprayer	332[c]	75-100
	1958	DDT	1	Aircraft	20	"satisfactory"
	1958	DDT	--	Hand sprayer	21	--
	1966	Malathion	0.8	Mistblower	14	"excellent"
					Total 1,924+	
Ottawa	1947	DDT	--	Hand sprayer	25	100
	1949	DDT	--	Hand sprayer	3	100
	1970	Malathion	0.5	Mistblower	1-E	84-100
					Total 29	
MIDLANDS						
Mark Twain	1941	Lead arsenate	--	--	0+	--
	1949	DDT	--	Hand sprayer	186	95
	1953	DDT	--	--	8	"no new infestation"
					Total 194+	
Shawnee	1946	DDT	1	Hand sprayer	113	80-90
	1947	DDT	0.5 & 1	Aircraft	5,267	5-85
	1947	DDT	1	Aircraft	447-E	"erratic"
	1947	DDT	0.5	Aircraft	438-E	"erratic"
	1947	DDT	0.25	Aircraft	64-E	"erratic"
	1948	DDT	--	Hand sprayer	8	80-100
	1949	DDT	--	Hand sprayer	30	80-85
					Total 6,367	
NORTHERN APPALACHIA						
Monongahela	1951	--	--	Hand sprayer	10	50
					Total 10	
Wayne	1941	Lead arsenate	--	Hand sprayer	186	satisfactory
					Total 186	
					Regional total 64,226+	

[a]Of the 10,636 acres, 4,260 were treated for redheaded and jack pine sawflies simultaneously.

[b]Treated for redheaded and jack pine sawflies simultaneously.

[c]Treated for redheaded pine sawfly and Saratoga spittlebug simultaneously were 251 of the 549 acres, all of the 449 acres, and 25 of the 332 acres.

JACK PINE BUDWORM

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			LAKE STATES			
hequamegon	1957	DDT	1	Aircraft	14,421	"very satisfactory"
	1961	DDT	1	Aircraft	2,400	78+
	1968	Mexacarbate	0.15	Aircraft	500-E	unsatisfactory
	1968	Aminocarb	0.15	Aircraft	500-E	"satisfactory"
				Total	17,821	
hippewa	1939	Lead arsenate	--	Hydraulic sprayer	0+	--
	1959	DDT	1	Aircraft	600	"successful"
	1960	DDT	1	Hydraulic sprayer	1,030	"very good control"
	1962	DDT	1	Aircraft	24,055	98
				Total	25,685+	
awatha	1950	DDT	1	Aircraft	320	95
	1951	DDT	1	Aircraft	4,358	95
	1962	DDT	1	Aircraft	12,598	satisfactory
				Total	17,276	
iron	1964	Malathion	1	Aircraft	80-E	64
	1964	Malathion	0.5	Aircraft	120-E	43
				Total	200	
inistee	1964	DDT	1	Aircraft	60-E	86
	1964	Malathion	1	Aircraft	60-E	85
	1964	Malathion	0.5	Aircraft	60-E	33
	1964	Mexacarbate	1	Aircraft	15-E	85
	1964	Dimethoate	0.5	Aircraft	15-E	95
	1966	Malathion	0.77	Aircraft	200-E	75
				Total	410	
perior	1939	Lead arsenate	--	Hydraulic sprayer	0+-E	"unsatisfactory"
				Total	0+	
				Regional total	61,392+	

MISCELLANEOUS INSECTS

ational forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			GRASSHOPPERS			
			LAKE STATES			
Hiwatha	1938	Arsenicals	—	Broadcast on ground	140	"very effective"
	1949	Ammonium sulphate	—	Broadcast on ground	30	80
				Total	170	

(Table continued on next page)

(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
Manistee	1936	Sodium arsenate	--	Broadcast on ground	18,293	"quite satisfactory"
	1937	--	--	Broadcast on ground	14,873	"quite satisfactory"
	1938	--	--	Broadcast on ground	3,025	--
	1939	Sodium arsenate	--	Broadcast on ground	400	--
	1940	--	--	Broadcast on ground	10,288	satisfactory
	1941	--	--	Broadcast on ground	1,944	--
	1942	--	--	Broadcast on ground	0+	--
	1948	Sodium fluosilicate	--	Broadcast on ground	415	80
	1949	Chlordane	0.15	Broadcast on ground	1,298	90
				Total	50,536+	
				Regional total	50,706+	
			WHITE GRUBS LAKE STATES			
Chippewa	1934	Lead arsenate	--	Dipped stock	43-E	"definite protection"
	1934	Calcium arsenate	--	Dipped stock	1-E	"definite protection"
				Total	44	
Hiawatha	1961	Aldrin	0.2	Planting machine	364	"erratic"
	1961	Aldrin	—	Dipped stock	533	"erratic"
	1962	Aldrin	0.2	Planting machine	1,227	"erratic"
	1962	Aldrin	0.3	Planting machine	456	"erratic"
	1962	Aldrin	--	Dipped stock	1,191	"erratic"
	1963	Aldrin	0.2	Planting machine	105	"erratic"
	1963	Aldrin	—	Dipped stock	2,596	"erratic"
	1964	Aldrin	0.2	Planting machine	76	"erratic"
	1965	Aldrin	0.2	Planting machine	885	"erratic"
	1965	Aldrin	0.2	Hand sprayer	342	"erratic"
	1966	Aldrin	0.2	Planting machine	785	"erratic"
	1966	Aldrin	0.2	Hand sprayer	259	"erratic"
	1966	Aldrin	0.1	Hand sprayer	297	"erratic"
	1966	Aldrin	0.1	Planting machine	80	"erratic"
	1967	Aldrin	0.2	Planting machine	552	--
	1967	Aldrin	0.2	Hand sprayer	86	--
	1967	Aldrin	3.2	Planting machine	140	--
	1967	Aldrin	0.1	Planting machine	2-E	satisfactory
	1967	Aldrin	0.3	Planting machine	3-E	satisfactory
	1967	Aldrin	0.1	Hand sprayer	2-E	satisfactory
	1967	Aldrin	0.2	Hand sprayer	3-E	satisfactory
	1967	Aldrin	3.2	Planting machine	5-E	satisfactory
				Total	9,989	
Nicolet	1960	Aldrin	--	Dipped stock	516	--
	1961	Aldrin	—	Dipped stock	365	--
	1962	Aldrin	—	Dipped stock	1,488	--
				Total	2,369	
Ottawa	1962	Aldrin	--	Dipped stock	232	--
				Total	232	
				Regional total	12,634	

(Table continued on next page)

(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			PINE TUSSOCK MOTH			
			LAKE STATES			
Chequamegon	1962	DDT	1	Aircraft	8,735	87-99
				Regional total	8,735	
			JACK PINE SAWFLY			
			LAKE STATES			
Manistee	1939	Lead arsenate	—	—	4,260[a]	--
	1939	Lead arsenate and Nicotine sulphate	--	—	300[a]	--
	1939	Nicotine sulphate	—	—	680[a]	--
				Regional total	5,240	
			SPRUCE BEETLE			
			NEW ENGLAND			
Green Mountain	1937	Copper sulphate	—	Injection	4,719	"not effective"
				Regional total	4,719	
			FOREST TENT CATERPILLAR			
			LAKE STATES			
Chippewa	1936	Lead arsenate	—	Hydraulic sprayer	8	"successful"
	1937	Lead arsenate	—	Hydraulic sprayer	442	"very satisfactory"
	1938	Lead arsenate	—	Hydraulic sprayer	47	successful
	1951	DDT	1	Aircraft	664	80
	1952	DDT	1	Aircraft	519	80
				Total	1,680	
Superior	1936	Lead arsenate	11.2	Hydraulic sprayer	195	"very successful"
	1937	Lead arsenate	10.8	Hydraulic sprayer	80	"excellent"
	1937	Lead arsenate	9.9	Hydraulic sprayer	155	"excellent"
	1938	Lead arsenate	—	Hydraulic sprayer	22	successful
				Total	452	
				Regional total	2,132	
			GYPSY MOTH			
			LAKE STATES			
Manistee	1974	Carbaryl	0.8	Aircraft	800	successful
				Total	800	
			NEW ENGLAND			
White Mountain	1954	DDT	1	Aircraft	410	--
	1970	Carbaryl	1	Mistblower	15	--
	1972	Carbaryl	1	Mistblower	12	--
				Total	437	
				Regional total	1,237	
			LOBLOLLY PINE SAWFLY			
			MIDLANDS			
Mark Twain	1965	Malathion	--	--	0+	"partial control"
				Total	0+	
Shawnee	1957	DDT	1	Aircraft	1,135	96-100
				Total	1,135	

(Table continued on next page)

(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
				Regional total	1,135+	
			EUROPEAN PINE SHOOT MOTH			
			LAKE STATES			
Manistee	1952	DDT	--	Mistblower	108	90
	1957	DDT	7	Hydraulic sprayer	84-E	90
	1958	DDT	7	Mistblower	53	"fair"
	1958	DDT	10	Mistblower	150	"fair to very good"
	1960	Malathion	2	--	404	"not satisfactory"
	1960	Naled	--	--	14	--
	1962	DDT	2	Hydraulic sprayer	10-E	72 and 84
	1962	DDT	2	Mistblower	4-E	36
	1962	DDT	4.5	Mistblower	3-E	0
				Total	830	
			NORTHERN APPALACHIA			
Allegheny	1951	DDT	4	Aircraft	71	"disappointing"
	1959	Phorate	2	Aircraft	20-E	"successful"
	1959	Malathion	1	Aircraft	25-E	95
				Total	116	
				Regional total	946	
			WHITE PINE WEEVIL			
			LAKE STATES			
Chequamegon	1963	Lindane	--	--	0+	--
				Total	0+	
Manistee	1950	DDT	1	Aircraft	80-E	78+
	1950	DDT	2	Aircraft	320-E	99
	1951	DDT	--	Aircraft	0+	--
				Total	400+	
Nicolet	1962	Lindane	0.13	Mistblower	5-E	"little control"
	1962	Lindane	0.05	Mistblower	5-E	"little control"
				Total	10	
Ottawa	1958	Lindane	0.05	Hand sprayer	23-E	100
	1959	Lindane	1	Aircraft	50-E	--
	1959	Lindane	0.13	Hand sprayer	3-E	--
	1962	Lindane	0.05	Mistblower	5-E	"no signficant reduction
	1962	Lindane	0.03	Mistblower	5-E	"no significant reductior
				Total	86	
			NORTHERN APPALACHIA			
Allegheny	1958	Lead arsenate	--	Hand sprayer	75	--
	1959	DDT	2	Aircraft	115-E	"effective"
				Total	190	
				Regional total	686+	

(Table continued on next pag

(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			LARCH SAWFLY LAKE STATES			
Chippewa	1948	DDT	0.6	Aircraft	100-E	"not conclusive"
	1949	DDT	1	Aircraft	80-E	"quite effective"
					Total 180	
Superior	1950	DDT	1	Aircraft	200-E	62-70
					Total 200	
			NORTHERN APPALACHIA			
Allegheny	1940	Lead arsenate	—	Hand sprayer	4	--
	1941	Lead arsenate	—	Hand sprayer	4	--
	1967	Malathion	0.7	Aircraft	54	--
	1967	Malathion	0.8	Aircraft	54	--
					Total 116	
Monongahela	1959	DDT	--	--	1	100
	1965	Malathion	--	--	0+	--
					Total 1+	
					Regional total 497+	
			CHERRY SCALLOPSHELL MOTH NORTHERN APPALACHIA			
llegheny	1974	Carbaryl	1	Aircraft	150-E	--
	1974	Carbaryl	2	Aircraft	75-E	--
					Regional total 225	
			WALKINGSTICK LAKE STATES			
icolet	1950	DDT	1	Aircraft	210	99
					Regional total 210	
			REDHUMPED OAKWORM LAKE STATES			
anistee	1973	Resmethrin	0.03	Aircraft	30-E	--
	1973	Malathion	0.9	Aircraft	30-E	--
	1973	Carbaryl	1	Aircraft	30-E	"most effective"
	1973	Mexacarbate	1.5	Aircraft	30-E	--
					Regional total 120	
			BLACK TURPENTINE BEETLE MIDLANDS			
ark Twain	1960	Orthodichlorobenzene	--	--	12	--
	1965	Benzene hexachloride	0.4	Hand sprayer	62	--
	1967	Benzene hexachloride	--	Hand sprayer	0+	--
					Total 74+	
			NORTHERN APPALACHIA			
nongahela	1965	Benzene hexachloride	--	Hand sprayer	10	--
					Total 10	
					Regional total 84+	

(Table continued on next page)

(Table continued)

National forest	Year treated	Insecticide	Rate	Application method	Acres treated	Results
			Pounds/acre			*Numbers in percent*
			YELLOWHEADED SPRUCE SAWFLY			
			LAKE STATES			
Superior	1968	Malathion	0.5	Mistblower	61	—
					Regional total 61	
			PINE TORTOISE SCALE			
			LAKE STATES			
Nicolet	1954	DDT	2	Aircraft	25-E	successful
	1954	Lime sulphur	—	Hydraulic sprayer	28	90
					Regional total 53	
			VIRGINIA PINE SAWFLY			
			NORTHERN APPALACHIA			
Wayne	1961	DDT	—	Mistblower	2	"good control"
	1962	DDT	—	Mistblower	7	—
	1963	DDT	—	Mistblower	10	"effective"
	1964	Malathion	—	Mistblower	10	—
					Regional total 29	
			RED TURPENTINE BEETLE			
			LAKE STATES			
Hiawatha	1966	Lindane	0.2	Hand sprayer	20	successful
					Regional total 20	
			EUROPEAN PINE SAWFLY			
			MIDLANDS			
Hoosier	1950	DDT	—	Hand sprayer	12	96
					Total 12	
			NORTHERN APPALACHIA			
Wayne	1966	Malathion	—	—	0+	—
					Total 0+	
					Regional total 12+	
			PITCH PINE TIP MOTH			
			NORTHERN APPALACHIA			
Monongahela	1951	—	—	Hand sprayer	4	100
					Regional total 4	
			NANTUCKET PINE TIP MOTH			
			MIDLANDS			
Shawnee	1946	DDT	—	—	0+-E	—
	1947	—	—	—	1-E	—
	1948	DDT	—	Hand sprayer	1-E	"excellent"
	1949	—	—	—	0+-E	—
					Regional total 2+	
			FALL CANKERWORM			
			NORTHERN APPALACHIA			
Allegheny	1966	Carbaryl	—	Aircraft	0+	—
					Regional total 0+	

[a]Redheaded and jack pine sawflies were treated simultaneously.

APPENDIX III

DDT[34]

The Forest Service is very much interested in any new insecticides or other developments which may be helpful in reducing the heavy drain on forest growth caused by insect infestations. These losses have been very extensive, in some areas the insects destroying valuable stands of timber over thousands of acres. Well known examples are the spruce budworm infestation in the Lake States, the Northeast and Canada, the larch sawfly epidemic which covered the range of eastern larch from the Lake States to the Atlantic, and the bark beetle attacks in the pine stands of the West. Bark beetles, defoliators and other forms of insects harmful to the forests account for a heavy toll, and must be considered along with fire and disease as enemies of the forest. Moreover, insect-killed trees add measurably to the problem of fire control and affect the usefulness and beauty of the forests.

Various control measures have been applied in the past, but there has never been anything in the insecticide field which offered the advantages which may come with DDT. For most insects destroying forest trees there has not been a practical method of control, since highly toxic materials were not available in a form which could be readily applied over large areas. Arsenicals, for example, have offered the most hope, but their use has been of a limited nature because of the cost of materials, the labor needs, and the hazards to all forms of animal life, including man.

The Forest Service, however, is fully aware of the hazards which accompany the use of a potent insecticide. The Service is also cognizant of the public concern over the wide use of a new poison which has not been subjected to exhaustive tests. We appreciate that studies have revealed that all insects are not equally susceptible, that beneficial insects as well as harmful species are killed, and that cold blooded animals are more or less affected. The knowledge that aquatic insects may be wiped out and that trout may be killed have added to the need for careful consideration in the use of DDT in regions where fishing is an important form of recreation.

The answers to the many technical questions should come from the carefully conducted studies of the Bureau of Entomology and Plant Quarantine and the Fish and Wildlife Service. Both of these agencies have conducted studies or made observations on the use of DDT on national forest lands during the past season. Although the Forest Service performs research work in the field of forest management, forest products, and range management, it looks to the Bureau of Entomology and Plant Quarantine for investigations in the field of forest insects, and to the Fish and Wildlife Service for research on forest wildlife. Under this procedure field trials of DDT were carried out by the Bureau of Entomology with the cooperation of the Fish and Wildlife Service and the Forest Service on several national forest areas. These were for Saratoga spittlebug on Jack pine plantations in the Nicolet Forest in Wisconsin, pinetip moth on Ponderosa pine in the Nebraska Forest in Nebraska, and spruce budworm on pine and fir in the Roosevelt National Forest in Colorado. The results of these tests, plus work on other areas have been mentioned here today by representatives of these two Bureaus.

On the forest management side, the Forest Service has been conducting research designed to develop cutting procedures and other practices which would be helpful in controlling harmful insects or in rendering them endemic without recourse to insecticides. In approaching the problem attention has been given to the nature of the attacks, including such factors as age, vigor, composition, past treatment, and growing condition of the forest stand. Two important considerations are kept in mind, (1) what cutting practices can be used to hold the insect epidemics to a minimum, once the attack is expected or already in effect and (2) what treatment within economic limits can be applied in cutting, thinning, and otherwise to develop a natural resistance to the insect attacks. In the case of the spruce budworm for example, it is known that an abundance of good sized balsam fir in a stand consitutes a condition favorable for the development of an epidemic whereas young and vigorous spruce, by themselves, are resistant to attack. Therefore cutting practices which provide for rather frequent cycles, removing all merchantable balsam fir in each cutting, help to maintain a young, highly productive stand resistant to this insect. In fact it has been felt by many workers that the hope for practical and lasting control of many harmful forest insects will be found in the adaptation of cutting practices which will build stand resistance.

[34] *Statement by Lloyd W. Swift, Chief, Division of Wildlife Management, USDA Forest Service, at 41st Annual Convention of the National Audubon Society, New York City, October 22, 1945.*

At this time the Forest Service is in no position to define the limits of usefulness of DDT in its work. We intend to consider fully both its advantages and disadvantages under the widely varying conditions which we have to meet. The insecticide appears to have real promise for application to forest areas by plane, and therefore may be a material which can be used in increasing the productivity of the forests. Information on the effect on destructive insects will be weighed against the conditions on the ground such as the presence or absence of trout waters, and other valuable or unusual wildlife forms. But before its use is fully accepted, the Service would want to know what can be expected under a given set of conditions—what forms of beneficial life, insects, birds, amphibians, fishes, etc. would be endangered and to what extent.

Fowler, Richard F.; Wilson, Louis F.; Paananen, Donna M.
Insect suppression in Eastern Region national forests: 1930-1980. Gen. Tech. Rep. NC-103. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 56 p.

Reports on insect suppression in 16 Eastern Region national forests over a 50-year period. Identifies 27 target insects attacked, insecticides used, acreages treated, and results obtained by suppression attempts. Notes that only 3.4 percent of Eastern national forest land has been chemically treated during the years studied.

KEY WORDS: Pesticides, insecticides, pest management, cultural control, DDT, arsenicals.

1966-86

NORTH CENTRAL

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